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# RECOVERY OF GASOLINE FROM UNCONDENSED STILL VAPORS

BY

D. B. DOW

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# RECOVERY OF GASOLINE FROM UNCONDENSED STILL VAPORS.

By D. B. Dow.

## INTRODUCTION.

The Bureau of Mines through cooperative endeavor has attempted to aid the adoption by the petroleum industry of practices more efficient than those in general use. In collecting and disseminating information on improved methods of producing crude petroleum and of recovering gasoline from natural gas, the bureau has sought to arouse interest in the efficiency of the methods used in all phases of the oil and gas industries. At petroleum refineries the tendency toward higher efficiency is increasing, and data on improved practices, it is believed, will be of especial value to small refiners unable to carry on extensive experiments.

During 1920[1] the refineries of the United States required 433,915,029 barrels of crude oil, including 61,136,210 barrels of Mexican crude. This crude yielded 4,882,546,599 gallons of gasoline, an average daily production of 13,340,291 gallons. Besides the gasoline obtained from crude oil by fractional distillation and from heavy oils by cracking, this total included 3,152,924 barrels of natural-gas gasoline which was purchased by refiners and blended with the gasoline from the other two sources.

This paper aims to show the possibility of increasing the gasoline yield from the crude by the recovery of considerable gasoline that is now lost by remaining uncondensed. This loss will tend to become larger in the future because, on account of the growing tendency to eliminate evaporation losses in handling crudes in the field, refineries will receive crudes containing much lighter and more volatile fractions. The magnitude of the losses resulting from noncondensation of still vapors has been realized by only a small proportion of the refiners and comparatively few plants have installed recovery systems.

In 1920 the 13 refineries studied in collecting data for this report were obtaining 128,651 gallons of gasoline daily by recovering the gasoline contained in uncondensed still vapors. These plants are situated in various refining centers other than on the Pacific coast, and are running crudes that represent all the producing fields of the United States east of the Rocky Mountains. In addition, several are running Mexican crude. Information from refining companies in California indicates that, because of the smaller gasoline content of the crudes received, there are no large plants for recovering uncondensed still vapor in that State.

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[1] Mason, H. F., Refinery statistics for 1920: Bureau of Mines.

## ACKNOWLEDGMENTS.

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H. H. Hill, former superintendent of the petroleum experiment station of the Bureau of Mines at Bartlesville, Okla., outlined plans for the investigation and has been in close touch with it from the beginning. His many suggestions, and those of E. W. Dean, former petroleum chemist of the bureau, have been of great value. N. A. C. Smith, petroleum chemist of the bureau, also offered helpful suggestions.

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## DISTILLATION OF PETROLEUM.

### PHYSICAL AND CHEMICAL CHARACTERISTICS OF PETROLEUM HYDROCARBONS.

Crude petroleum is composed chiefly of a large number of different hydrocarbons each with its own physical characteristics, such as boiling point and specific gravity. Besides these hydrocarbons, the crude contains derivatives of sulphur, oxygen, and nitrogen which may be considered as impurities. The hydrocarbons belong to different chemical series, those of the paraffin series having the general formula $C_nH_{2n+2}$ predominating in the paraffin or mixed base crudes from the Eastern, Mid-Continent, and Rocky Mountain fields. The naphthene-base crudes of the Gulf coast and California fields consist largely of hydrocarbons of the naphthene series, having the general formula $C_nH_{2n}$. Some crudes contain small amounts of unsaturated hydrocarbons of the olefin series ($C_nH_{2n}$) and some contain aromatic hydrocarbons of the benzine series ($C_nH_{2n}-6$).

The hydrocarbons comprising the gasoline and gas considered in this paper are for the most part of the paraffin series, although gases from cracking stills contain relatively high percentages of unsaturated hydrocarbons and appreciable amounts of hydrocarbons that belong to the benzine series. Of the hydrocarbons of the paraffin series, the lower members, methane ($CH_4$), ethane ($C_2H_6$), propane ($C_3H_8$), normal and iso-butane ($C_4H_{10}$) and one of the pentanes ($C_5H_{12}$) are gases at ordinary temperatures, having boiling points of −265° F. (−165° C.), −135° F. (−93° C.), −49° F. (−45° C.), and + 34° F. (1° C.), respectively. Normal pentane (boiling point, 97° F.), normal hexane (boiling point, 154° F.), normal heptane (boiling point, 190° F.), and normal octane (boiling point, 259° F.) are the main constituents of the gasoline recovered from still vapors, although these vapors contain a certain proportion of some of the lower members of the series present as dissolved gases, and certain higher members that are carried over in still vapors either mechanically or as a result of the partial-pressure effect. Each succeeding member of the paraffin series has a higher boiling point. Hexadecane, for example, has a boiling point of 549° F., whereas pentane boils at 97° F.

## DISTILLATION OF CRUDES IN THE LABORATORY.

By fractional distillation crude oil can be separated into cuts or fractions containing mixtures of hydrocarbons having similar physical properties. In the distillation of crude oil, even in the laboratory, complete separation of individual hydrocarbons is exceedingly difficult, unless countless refractionations are made. A sample of the distillate driven over between any two given temperatures will, when redistilled, show the presence of hydrocarbons boiling at temperatures lower as well as higher than the limits of the previous distillation. This is because the boiling point of each hydrocarbon in a mixture of hydrocarbons is influenced by the presence of the other hydrocarbons.

In the distillation of crude oil hydrocarbons of the lowest boiling points are vaporized first; consequently the first fraction has a much higher concentration of low-boiling hydrocarbons than the original liquid. Because of high percentage of low-boiling constituents, this fraction is the most difficult to condense, for its temperature of liquefaction is low. As the distillation progresses the temperature required to vaporize the remaining hydrocarbons becomes higher, and consequently the resulting vapor is more easily condensed.

In order to condense the vapors formed by heating crude oil, the same amount of heat must be removed from the vapor as was necessary to change it from the liquid to the vapor state. In the refinery this cooling is done by leading the vapors through coils of pipe submerged in water. The heat in the vapor is transferred to the water and the vapor liquefies. However, a certain proportion of this vapor, because of insufficient cooling or because of its having a condensing point lower than that of the temperature of the water, remains uncondensed. Certain other fractions do not condense because the liquefaction points of their component hydrocarbons are affected by the presence of other hydrocarbons. A small part of this vapor is dissolved in the liquid that has condensed.

## METHODS OF DISTILLATION IN PETROLEUM REFINERIES.

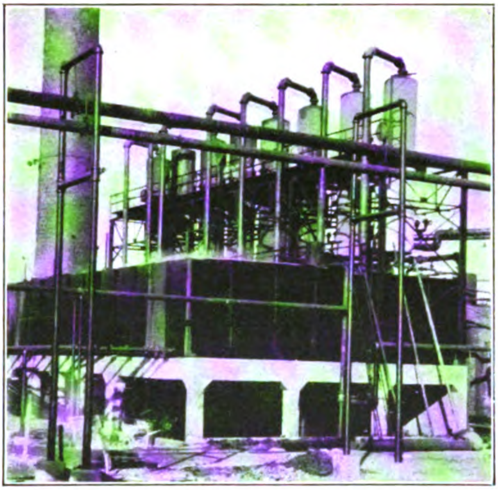
### FIRE DISTILLATION.

In the first step of refining the separation of crude oil into its various products is accomplished by a fractional distillation, or what is more commonly termed a "fire distillation." A still is charged with crude oil and heated directly with fire. The "fire stills" are horizontal, riveted or welded steel shells mounted on brick settings. In many stills the part that is exposed to the air is covered with insulating material. A vapor line connected to the top of each still carries the hot vapors to the condenser coils, whence "run down" lines carry the condensed liquid to the receiving house or "tail house.". These run-down lines feed the condensed liquid or "stream" into the "look-box," from whence the distillate is distributed to the proper receiving tanks by means of pipe manifolds.

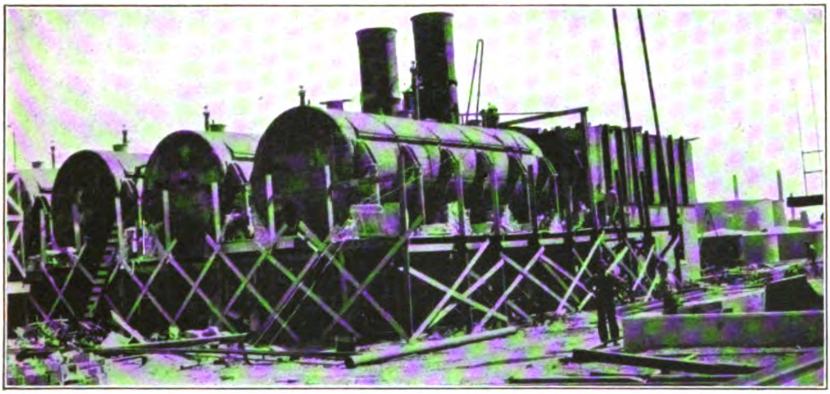
### "BATCH" AND CONTINUOUS PROCESS OF DISTILLATION.

Formerly in this country all crude petroleum was distilled in "batch" stills, from which the different fractions, such as crude benzine, kerosene, distillates, and gas oil, are successively obtained as the temperature of the charge is raised. The "batch" method of distillation is used exclusively where crude oil is run down to coke and in reducing paraffin-base crudes to cylinder stocks. It is also used to some extent for obtaining wax distillates from the residue from continuous crude stills. Stills employed for the latter purpose are commonly known as "tar stills." Plate I, *B*, shows a battery of tar stills under construction.

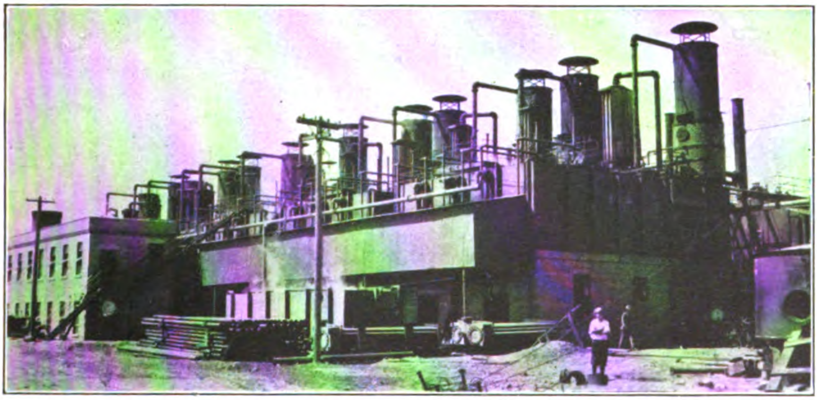
In the continuous process, crude oil is pumped into the first of a battery of stills (illustrated in Plate II), passes successively through each still, and is finally discharged as residuum from the last. Each successive still is kept at a higher temperature than the preceding one. Fractions from each still in the battery do not change from lighter to heavier products, as in the batch process, but have fairly uniform gravities and boiling points during the entire time that the battery is in operation. For example, a battery of continuous stills handling average Mid-Continent crude gives cuts of light naphtha, heavy naphtha, kerosene, and gas oil in the order named. The con-



*A*.—CONDENSERS. (NOTE STEAM RISING FROM CONDENSER WATER.)



*B*.—BATTERY OF FOUR STILLS UNDER CONSTRUCTION.



*C*.—CONDENSERS; GAS RISERS FROM RUN-DOWN LINES.

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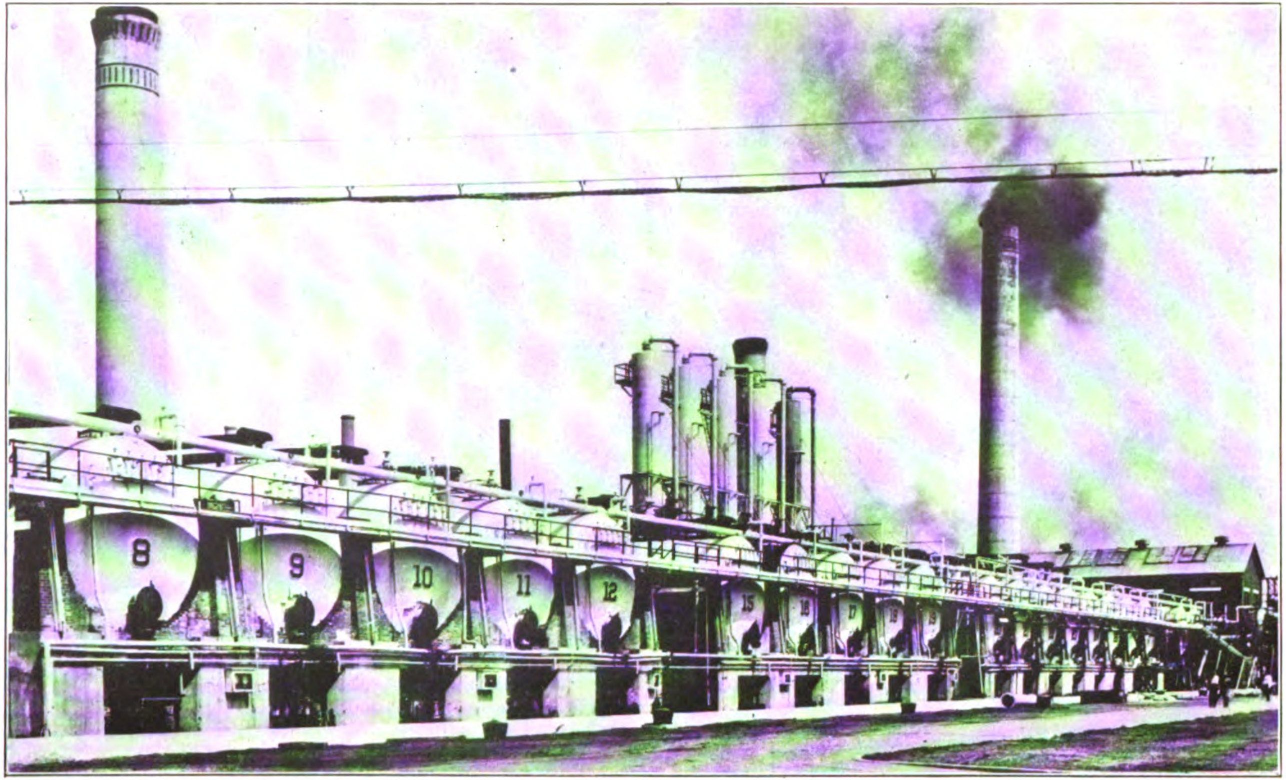
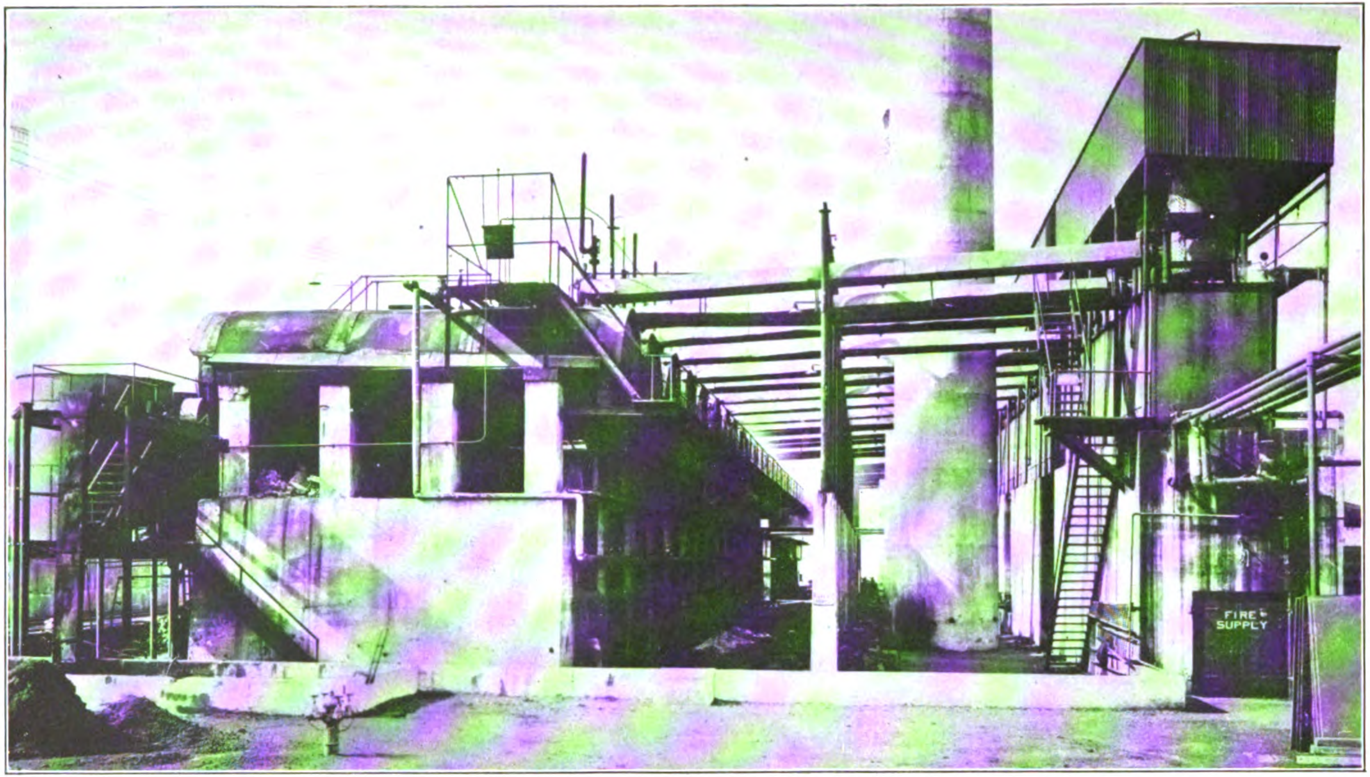


COSDEN & CO., TULSA, OKLA., BATTERY OF 20 CRUDE-OIL STILLS CAPABLE OF HANDLING 10,000 TO 25,000 BARRELS A DAY.



STANDARD OIL CO. OF KENTUCKY, LOUISVILLE, KY., BURTON CRACKING STILL.

tinuous process also includes the method of distilling oil in pipe stills. In this process the oil is pumped continuously through heated pipes, from which the vapors are taken off and the different fractions condensed

### STEAM COILS.

Both the "batch" and the "continuous" stills of the shell type are generally equipped with steam coils perforated so that steam is directed against the bottom of the still. These perforations tend to distribute the steam evenly through the body of oil. The introduction of steam agitates the oil and thus minimizes cracking because the oil does not have opportunity to become locally overheated through long contact with the still shell. The added steam also aids distillation by carrying fractions over mechanically and by reducing the temperature at which the hydrocarbons distill.

### PRESSURE DISTILLATION.

Heavy oils decompose when distilled at temperatures above their normal boiling points, and the distillate is made up of hydrocarbons that have much higher Baumé gravity and lower boiling points than the original oil.

If heavy oil is distilled under pressure the decomposition point can be reached before the temperature of the charge attains the boiling point of the oil at the pressure in question.

The decomposition of an oil by heat is commonly known as "cracking" and the stills in which this operation is conducted are known as "cracking stills" or pressure stills (see Pl. III). Distillation under pressure is commonly used for producing gasoline and light distillates from heavy oils, such as gas oil. Because of the decomposition that takes place, the products obtained contain a relatively high proportion of unsaturated hydrocarbons.

### STEAM DISTILLATION.

After the fractional distillation by fire stills, the light distillates obtained are treated in agitators with acid and caustic, and then made marketable by redistilling in steam stills. A steam still is of the same general construction as a fire still, but has a larger number of perforated steam coils. Distillation in it is largely accomplished by the use of steam, although a fire is sometimes kept beneath a steam still in order to regulate the distillation. Because of the steam, as indicated above, the hydrocarbons distill at temperatures much below their normal boiling points. Much closer cuts are obtained in this way than by fractional distillation of the crude oil. Distillation by steam may be conducted either as a "batch" or continuous process.

## CONDENSATION OF DISTILLATES.

In order to convert the vapors coming from the still into liquids it is necessary to remove the heat of vaporization. This removal of heat is known as condensation, and in the refinery is accomplished by (1) aerial condensation, or (2) condensation in submerged coils.

### AERIAL CONDENSATION.

By passing the vapor from the stills through pipes or shells having large surfaces exposed to the air, considerable condensation can be effected. This method is employed in the aerial condensers used in connection with pressure stills. The heavier fractions condense and drain back into the still where they are again subjected to cracking. In fractionating towers, or dephlegmators, aerial condensation is also employed for separating the distillates into fractions having comparatively narrow boiling ranges.

### CONDENSATION IN SUBMERGED COILS.

The common method of condensation is by means of coils, either in series or parallel, submerged in a condenser box through which water flows. These coils are smaller in diameter at the bottom of the box than at the top, because the liquid condensate occupies less space than the vapors. Water circulates through the condenser box, the cold water entering at the bottom and the warm water discharging at the top. The amount of water circulated is based on the heat transfer necessary to condense the vapors passing through the coils. Plate I, *A* (p. 4), shows condenser boxes as well as towers in which aerial condensation takes place.

## NATURE AND AMOUNT OF UNCONDENSED VAPORS.

### UNCONDENSED VAPORS FROM DIFFERENT DISTILLATION PROCESSES.

Vapors remaining uncondensed after passing from the still through the condenser are generally classified under two heads, "sweet gas" and "sour gas." The term "sweet gas" refers to those vapors remaining uncondensed during the distillation of the lighter ends of the crude. In the batch process these vapors are formed from the light and heavy naphthas; in the continuous process they come from the first few stills of the battery, as these remove the light and heavy naphthas. The term "sour gas" refers to vapors formed by cracking, either in tar stills or in pressure stills; the term is very descriptive because cracked gases are largely unsaturated and have the marked odor peculiar to cracked products. This odor is due in part to the sulphur compounds usually present in cracked gases.

The distillation process used not only governs the properties of the gas but also the amount that is formed from a definite amount of crude. A skimming plant that removes only gasoline, kerosene, and gas oil will not produce the same amount of vapor as a plant that is equipped with pressure stills or one that is producing comparatively large quantities of cracked gases in distilling down to coke.

### UNCONDENSED VAPORS IN SKIMMING PLANTS.

In skimming plants practically all the vapors that remain uncondensed are formed during the distillation of the first 15 per cent of the crude. After this fraction has been removed, the vapors consist largely of hydrocarbons that can be readily condensed at the temperatures maintained in the ordinary condenser. In addition to the uncondensed vapor from the crude stills, large quantities of vapor remain uncondensed when the naphtha fractions are rerun in the steam stills.

With these two sources of gas, it is rather inexpensive to install gas lines to remove the vapors as rapidly as formed. The problem of collecting the vapors is correspondingly simple, for the lines from both sources can be joined and taken to a central point where a small vacuum is held. This is illustrated in Figure 1, which shows the layout of a typical skimming plant.

The gas can be treated either by the compression or absorption process. There is generally no need for "scrubbing" to remove sulphur, as the sulphur content of the gas from the naphtha fractions of the crude is low and is not objectionable. In some plants an even simpler installation is used—a 6-inch header into which the gas passes under its own pressure. This header is cooled by sprays, and a considerable quantity of gasoline is recovered. The gas is nearly all gasoline vapor, containing no appreciable amount of permanent gas; tests have shown it to contain as much as 30 gallons of gasoline per 1,000 cubic feet of vapor. In other words, as high as 90 per cent of the vapor can be condensed and held as gasoline. In the plants visited by the writer an average of about 7 gallons per 1,000 cubic feet was obtained.

### UNCONDENSED VAPORS IN REFINERIES WITH PRESSURE STILLS.

In refineries operating pressure stills the conditions are different from those at skimming plants. Uncondensed vapors are obtained not only from crude and steam stills but also from pressure stills. Large amounts of rich uncondensed vapor are also obtained from the rerunning of pressure-still distillate, which yield as high as 24 gallons of gasoline per 1,000 cubic feet. Experiments have shown that in running a barrel of Cushing crude about 52 cubic feet of vapor remains uncondensed. Under the same conditions of condensation a barrel of gas oil distilled under pressure gave 163 cubic feet of gas with an average gasoline content of 2.8 gallons per 1,000 cubic feet.

In distillation under pressure large quantities of fixed gases are formed. These fixed gases can not be condensed except under high pressures and very low temperatures. When the gas from cracking stills is added to that from the crude oil and steam stills, the gasoline content of the mixture is lower than that of the gas from the latter two sources. The volume of gas, however, will be increased to such an extent that the total amount of gasoline recovered will be considerably larger.

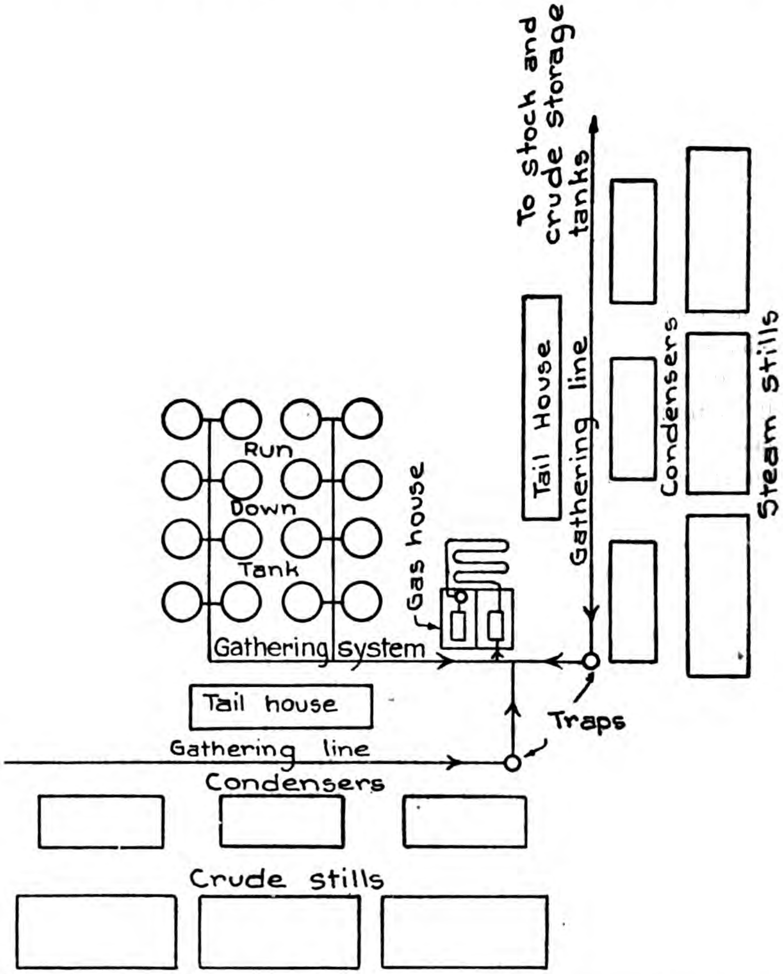


FIGURE 1.—Layout of skimming plant. Crude and steam stills for gathering gases from both batteries as well as a gathering system for gases evaporated from run-down, stock, and crude storage tanks.

As the sources of gas are more widely separated, the problem of installing a recovery system in a refinery of this kind is much more complicated than in a skimming plant. In the latter, the gathering

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line takes gas only from the crude stills that are running light distillates and from the steam stills; whereas in the complete refinery, the gases are obtained from crude, steam, pressure, and rerun stills. The larger number of sources involves a much more extensive system of gathering lines, and careful provision must be made for covering distances longer than those in skimming plants. If the gases are all collected by one central exhauster, as is usually done, there is danger of too high a vacuum being held on the stills; through the frictional resistance of the lines and the small amounts of gas produced those stills at longer distances may be under no vacuum at all.

Sulphur must generally be removed in a refinery that uses pressure stills because the hydrocarbon-sulphur compounds are broken down at the existing temperatures and pressures. To avoid considerable trouble from subsequent deposition of sulphur, rather large expenditures must be made in providing scrubbers for sulphur removal.

## EFFECT OF ATMOSPHERIC TEMPERATURES ON CONDENSATION.

Atmospheric temperature is an important factor in connection with the production of gasoline from uncondensed refinery vapors. During winter months, when condensation of the vapors is more nearly complete, the production of the "gas" plant falls off somewhat. An unusual example of this is one skimming plant that produces about 6,000 gallons of compressing gasoline a day through the summer but only 500 gallons a day in the winter. Ordinarily the difference is far less, but at all plants the production tends to drop in cooler weather. Another factor that tends to reduce the winter production of those "gas" plants that recover the gasoline from the vapors of storage tanks is the lessened evaporation in those tanks during cold weather.

## OTHER FACTORS GOVERNING AMOUNT OF UNCONDENSED VAPOR.

Three other factors that determine the gasoline content of the uncondensed vapors are the nature of the still charge, the temperature of the stream, and the vacuum carried on the run-down lines.

The distillates from crude oil containing only a small proportion of low-boiling fractions condense readily; and the loss in uncondensed vapor from this type of crude is low, as compared with the losses from a crude with a high gasoline content. Likewise the amount of vapor remaining uncondensed during the distillation in the steam still depends upon the nature of the charge. For example, a light naphtha forms more gas than a heavier distillate.

The vacuum carried on the run-down lines influences the yield of vapor, since any increase in vacuum causes a corresponding decrease in the boiling points of the distillate. The vacuum carried should be as low as possible and serve only to remove the vapors formed, rather than to lower the boiling point of the charge being distilled.

The temperature of the stream is an important factor, for any increase in the temperature of the distillate causes a corresponding increase in the gasoline content of the gas. The temperature of the stream depends in turn on the temperature of the cooling water in the condenser and on the rate of distillation. The amount of condenser surface per gallon per hour is determined by these two factors. For light fractions the condenser surface is generally about 2 square feet per gallon per hour. If this figure is lowered the gasoline content of the vapors becomes higher, and if it is raised the gasoline content becomes lower, provided, of course, that the temperature of the cooling water is constant.

## GASOLINE RECOVERABLE FROM VAPORS.

### EXPERIMENTS ON FRACTIONAL DISTILLATION.

In an effort to determine as nearly as possible the effect of the temperature of the stream on the uncondensed gasoline, a series of runs was made in the experimental refinery of the Bureau of Mines at Bartlesville, Okla. Cushing crude of a gravity of 38.5° B. was used, and a condenser surface of 2 square feet per gallon per hour was allowed. The vapors were drawn off under a vacuum of 2 inches of water and collected in a small test absorber that was filled with mineral seal oil as an absorbent.

After each test run was completed the gasoline was distilled from the absorbing oil by the usual laboratory method. Table 1 and Figure 2 show the results obtained. It will be noted that the amount of gasoline obtained from the uncondensed vapors from the crude still increases as the temperature of the stream is raised. The amount of gasoline contained in the uncondensed vapors per barrel of crude charged to the still ranges from 0.05 gallon at a stream temperature of 75° F. to 1.01 gallons at a stream temperature of 120° F.

TABLE 1.—*Effect of stream temperature on the amount of gasoline recovered from uncondensed vapors from a barrel of Cushing crude.*

| Temperature of stream. | Gasoline per barrel, crude still. | Gasoline per barrel, steam still. | Total gasoline per barrel of crude charged. |
|---|---|---|---|
| ° *F.* | *Gal.* | *Gal.* | *Gal.* |
| 75 | 0. 05 | 0. 13 | 0. 18 |
| 84 | . 08 | . 12 | . 20 |
| 90 | . 15 | . 09 | . 24 |
| 98 | . 36 | . 04 | . 40 |
| 109 | . 66 | . 01 | . 67 |
| 116 | . 88 | . 02 | . 90 |
| 120 | 1. 01 | . 03 | 1. 04 |

The gasoline produced from the crude still at each stream temperature shown was redistilled in the steam still, where the same stream temperature was maintained. For example, the stream temperature of the gasoline coming from the steam still was held at 75° F. on the gasoline produced from the crude stills at a stream temperature of 75° F.; a stream temperature of 90° F. was maintained on gasoline produced at a stream temperature of 90° F., and so on. Column 3 of Table 2 shows that the yield of gasoline from the uncondensed vapors from the steam still decreases as the temperatures of the stream increases. This can be explained by the fact that when the stream from the crude still has a temperature of about 75° F., the vapors are cooled so much that very little gasoline

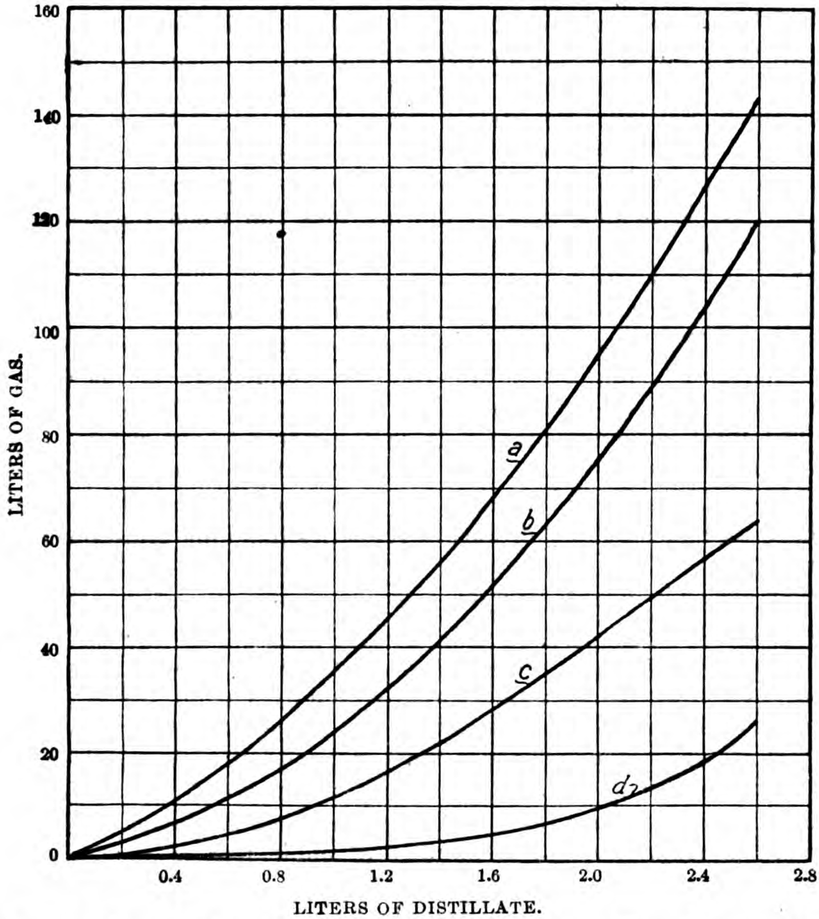

**Figure 2.**—Diagram showing volume of gases in cracking distillation: *a*, 150 pounds per square inch; *b*, 100 pounds per square inch; *c*, 50 pounds per square inch; *d*, atmospheric pressure.

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remains uncondensed. When this gasoline is introduced into the steam still, and is redistilled, with the stream running from the condenser at the same temperature, namely 75° F., the vapors contain a much greater concentration of high-gravity hydrocarbons than do the vapors from the crude and a larger volume of the vapors remains uncondensed.

With the stream running at 90° F. from both crude and steam stills, the amount of uncondensed vapors in the crude distillation is larger and in consequence the recovery of gasoline from the uncondensed vapors from the steam still is lower. In other words, the distillate charged to the steam still had been robbed of the lighter fractions and naturally the amount of vapors uncondensed in this distillation is smaller than in the previous run when the temperature of both streams was 75° F.

As the temperature of the stream from both stills increases, the quantity of uncondensed gasoline from the steam still decreases until at 120° F. practically all of the light fractions that will remain uncondensed have gone to the crude-still condenser, leaving only a very small amount uncondensed in the steam distillation.

The total gasoline obtained from the uncondensed vapors from both the crude still and from the steam still is shown in curve 3, Figure 3. This curve indicates the amount of gasoline that can be recovered under like conditions in refineries handling Mid-Continent crude.

The writer is indebted to Mr. Franklin Stroud, jr., of the Atlantic Refining Co., Philadelphia, for the following information on amounts of uncondensed vapor obtained from different crudes. Somerset and Mid-Continent crudes give approximately 4 cubic feet of vapor per barrel of crude charged, where the temperature of the stream is 70° F., whereas under the same conditions Mexican crude gives 3 cubic feet. The gasoline content of the vapor from the former crude is 12 gallons per 1,000 cubic feet and from the latter 10 gallons per 1,000 cubic feet. The number of cubic feet of uncondensed vapor varies 3 per cent for every 2° between 50° F. and 90° F., which gives the following formula for this range:

$$\text{Gallons per barrel} = \frac{A}{1000} \times (F \pm \frac{T}{2} \times 0.03)$$

where A represents the gallons of gasoline per 1,000 cubic feet (12 for Mid-Continent crude and 10 for Mexican crude); F the number of cubic feet at 70° F. for each crude (4 cubic feet for Mid-Continent and 3 cubic feet for Mexican crude); and T the degrees difference in the temperature of the stream from 70° F. This formula gives a straight-line curve which checks that part of curve 1, Figure 3, below

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90° F. Above 90° F. the formula would not be applicable for the amount of uncondensed gasoline increases more rapidly with each successive rise in temperature.

## EXPERIMENTAL RESULTS OF PRESSURE-STILL DISTILLATION.

On cracked gases, which include gases formed in running crude to coke, pressure-still gases and gases from running pressure-still distillates, Mr. Stroud gives the following data: Mexican light crude, 200 cubic feet of gas, per barrel charged, containing 4 gallons of gasoline per 1,000 cubic feet; Mid-Continent crude, 80 cubic feet of gas per barrel, containing 7 gallons per 1,000 cubic feet; average slop, 120 cubic feet per barrel, with 5 gallons of gasoline recoverable per 1,000 cubic feet; gas oil, in pressure-stills, 140 cubic feet per barrel, and a gasoline content of 3 gallons per 1,000 cubic feet, with a variation of 2½ per cent in the quantity of gas for every hour over or under 38 hours per 1,000 barrels.

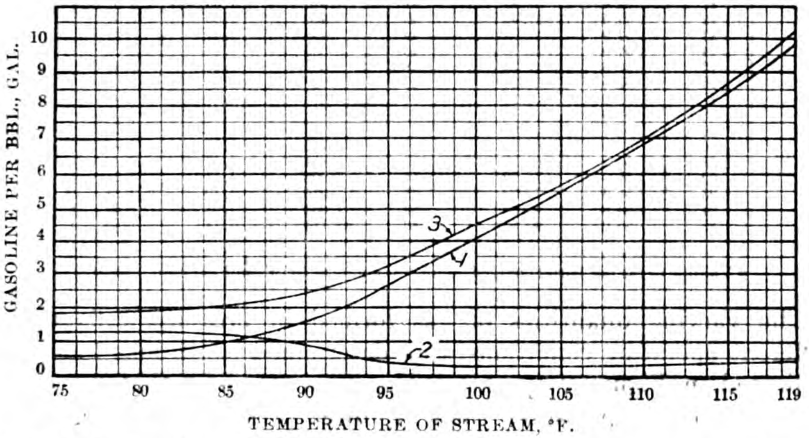

FIGURE. 3.—Diagram showing amount of gasoline uncondensed at different temperatures of stream: 1, Gasoline from uncondensed vapors in crude distillate; 2, gasoline from uncondensed vapors in steam distillate; 3, gasoline from uncondensed vapors per barrel of crude charged.

Tests conducted by Mr. A. J. Rodgers, of the Tide Water Oil Co., showed that in pressure-stills under an operating pressure of 95 pounds, a yield of 95 cubic feet of gas was obtained from each barrel charged. The specific gravity of this gas was about 0.85.

Mr. W. E. Espey, of Cosden & Co., Tulsa, Okla., furnished the writer with data, given in Table 2, on pressure-still gases. His figures show a larger volume of gas than those given by Mr. Stroud, but this disagreement is due to differences in type of still and in operation; in this case condensation took place at atmospheric pressure.

TABLE 2.—*Pressure-still operation.*

[Charge, 175 gallons; average pressure, 85 pounds; average temperature, 730° F. [Data supplied by W. E. Espey.]

| Duration of test. | Gravity of stream. | Quantity distilled. | Volume of gas formed during each period. | Total volume of gas. | Gravity of gas. | Yield of gasoline per 1,000 cubic feet. |
|---|---|---|---|---|---|---|
| *Hours.* | | *Galls.* | *Cu. ft.* | *Cu. ft.* | °*B.* | *Galls.* |
| 1 | 66.3 | 1.97 | 41 | 41 | 1.37 | 3.08 |
| 2 | 65.2 | 5.90 | 40 | 81 | 1.47 | 3.44 |
| 3 | 63.0 | 8.85 | 24 | 105 | 1.44 | 3.64 |
| 4 | 62.0 | 10.83 | 42 | 147 | 1.63 | 3.68 |
| 5 | 55.8 | 11.61 | 34 | 181 | 1.48 | 3.36 |
| 6 | 55.6 | 16.73 | 25 | 206 | 1.32 | 3.50 |
| 7 | 57.9 | 19.68 | 39 | 245 | 1.39 | 3.63 |
| 8 | 56.4 | 23.62 | 44 | 289 | 1.31 | 3.66 |
| 9 | 56.4 | 26.57 | 41 | 330 | 1.31 | 2.84 |
| 10 | 55.4 | 29.53 | 39 | 369 | 1.30 | 2.94 |
| 11 | 55.6 | 31.43 | 41 | 410 | 1.33 | 3.01 |
| 12 | 55.5 | 37.40 | 40 | 450 | 1.30 | 2.32 |
| 13 | 54.9 | 41.34 | 49 | 499 | 1.31 | 2.21 |
| 14 | 54.9 | 46.26 | 40 | 539 | 1.26 | 2.22 |
| 15 | 54.6 | 47.24 | 48 | 587 | 1.24 | 2.49 |
| 16 | 52.5 | 50.20 | 40 | 627 | 1.21 | 2.66 |
| 17 | 52.0 | 54.23 | 38 | 665 | 1.22 | 3.00 |
| 18 | 51.0 | 56.10 | 40 | 705 | 1.20 | 2.68 |
| 19 | 50.1 | 61.02 | 61 | 736 | 1.14 | 2.74 |
| 20 | 50.6 | 64.96 | 29 | 795 | 1.15 | 2.52 |
| 21 | 50.2 | 69.88 | 59 | 854 | 1.13 | 2.39 |
| 22 | 51.9 | 75.79 | 54 | 908 | 1.13 | 2.21 |
| 23 | 51.4 | 79.72 | 67 | 975 | 1.10 | 2.29 |
| 24 | 50.0 | 83.66 | 59 | 1,034 | 1.08 | 2.09 |
| 25 | 50.0 | 90.55 | 80 | [a]1,114 | 1.14 | 1.80 |

[a] Volume of gas per barrel charged equals 163 cu. ft. at 60° F. and 750 mm. pressure.

The varying quantities of gas formed in pressure stills under different operating conditions were determined by Brooks[2] and are indicated in Figure 2 (p. 11). These curves show that more gas forms at higher pressures than at lower pressures. The gasoline content of this gas probably decreases with higher pressures, although it depends on the temperatures maintained, the characteristics of the oil charged into the still, and the method of condensation.

## PLANT DATA ON RECOVERY OF GASOLINE FROM UNCONDENSED VAPORS.

The volume and the gasoline content of the gas formed in the operation of pressure stills differ appreciably from those of the uncondensed vapors formed in the fractional distillation of crude oil. A special study of the production of gasoline from uncondensed still vapors was made in a Mid-Continent refinery handling Cushing, Glenn pool, and Beggs crudes. The vapors were drawn from rundown lines leading from the crude stills and steam stills (there were no pressure stills in the plant) and from the "look boxes." Before entering the compressors the gas passed through a scrubber that collected all of the liquid condensed in the line by air cooling. This liquid, if allowed to enter the compressors, would have ruined lubrication. The vacuum held on the run-down lines was maintained by the intake of the two compressors (steam cylinder 10 inch by 12 inch, gas cylinder 12 inch by 12 inch). The gas was compressed to about 40 pounds per square inch and passed through coils in a cooling tower, where practically all of the gasoline was condensed, and collected in four accumulator tanks, each of 45 barrels capacity. The uncondensed gas then passed through two absorbers, in series that had been charged with naphtha having a gravity of 50° B. These absorbers were allowed to build up by absorption until full and were then blown into stock tanks.

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[2] Brooks, D. B. The cracking and distillation of petroleum under pressure: Jour. Franklin Inst. vol. 180, 1915, p. 653.

TABLE 3.—*Amount of gasoline obtained from uncondensed still vapors in one refinery during a period of 328 days.*

| Month. | Crude charged. | Gasoline obtained from uncondensed vapors. | Gasoline per barrel crude charged. |
|---|---|---|---|
| | *Barrels.* | *Gallons.* | *Gallons.* |
| January | 97,517 | 24,890 | 0.2552 |
| February | 115,032 | 57,846 | .5082 |
| March | 113,828 | 43,878 | .3855 |
| April | 116,002 | 40,697 | .3508 |
| May | 102,056 | 50,595 | .4958 |
| June | 180,990 | 198,980 | 1.0990 |
| July | 150,286 | 119,413 | .7943 |
| August | 160,095 | 174,739 | 1.091 |
| September | 129,746 | 117,725 | .9074 |
| October | 123,170 | 30,126 | .2446 |
| November (23 days) | 102,021 | 55,774 | .5467 |
| Total 328 days | 1,390,743 | 914,663 | ............ |
| Average 1 day | 4,240 | [a] 2,789 | .6577 |

[a] Or 66.4 barrels.

Table 3 shows the amount of crude charged for the first 328 days of 1920, the amount of gasoline produced from the uncondensed still vapors, and the amount of gasoline recovered per barrel of crude charged to the stills. The largest production of gasoline and the highest yields are during the summer, the recovery during two months of that period amounting to more than a gallon of gasoline per barrel of crude charged. The average crude charge for the 328-day period was 4,240 barrels daily and the average recovery of gasoline in the gas plant was 2,789 gallons daily. In other words, over 0.65 gallon of gasoline was obtained by compression and absorption of the uncondensed vapors formed during the distillation of 1 barrel of crude. This amounts to 1.57 per cent of the crude charged.

The condenser surface for each still figures about 4.2 square feet per gallon of gasoline per hour, which is larger than usual in refineries; the advantage of more condensing surface is offset by the temperature of the water, which, as the water supply is not abundant, becomes rather high.

The average temperature of the streams over a three-day period in November was approximately 100° F. and the average yield for that month was 0.5467 gallon of gasoline per barrel of crude. This recovery is about a tenth of a gallon higher than that obtained from the same crude in the experimental refinery of the Bureau. (See Fig. 3, p. 13.)

In this plant there is no method of measuring the volume of the gas other than by calculating from the displacement of the compressor. Such calculation accounts for approximately 350,000 cubic feet of gas a day, and based on this figure the gas would have a gasoline content of about 8 gallons per 1,000 cubic feet. It is not possible by this method to calculate accurately the gasoline content of the gas. Estimating the volume of gas from compressor displacement is much less accurate than measuring it by meter; the air content of the gas varies from time to time and the quality of the gas changes during distillation. All these factors are important and must be taken into consideration in calculating the gasoline content of the gas.

Mr. A. J. Rodgers, of the Tide Water Oil Co., furnished the writer with the data given in Table 4, which shows the cubic feet of gas evolved per barrel of crude charged, and the yield of gasoline per 1,000 cubic feet of gas during a period of 11 months.

TABLE 4.—*Cubic feet of gas evolved per barrel of crude charged and yield of gasoline per 1,000 cubic feet.*

**Report for 11 months of 1921.**

**[Kind of crudes charged: No. 1, Pennsylvania; No. 2, Mid-Continent; No. 3, Mexican; No. 4, West Columbia.]**

| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **No. 1 crude:** | | | | | | | | | | | |
| **Barrels** | [a] 112,017.59 | [a] 68,001.38 | [a] 80,213.91 | [a] 72,535.38 | [a] 70,075.75 | [a] 76,093.57 | [b] 102,178.60 | [b] 82,032.20 | [a] 91,336.28 | [a] 80,386.04 | [a] 89,292.49 |
| **Per cent** | 18.45 | 15.10 | 19.16 | 17.39 | 15.86 | 17.21 | 33.68 | 29.79 | 24.27 | 11.80 | 22.97 |
| **No. 2 crude:** [c] | | | | | | | | | | | |
| **Barrels** | 300,889.46 | 208,740.70 | 103,495.29 | 155,574.18 | 145,113.04 | 130,781.23 | 67,097.19 | 112,908.02 | 218,313.93 | 228,652.86 | 120,890.70 |
| **Per cent** | 49.52 | 46.35 | 24.72 | 37.29 | 32.83 | 29.58 | 22.11 | 41.00 | 58.02 | 33.55 | 31.07 |
| **No. 3 crude:** [d] | | | | | | | | | | | |
| **Barrels** | 194,183.19 | 173,654.65 | 192,360.88 | 175,084.40 | 226,769.81 | 235,234.79 | 134,140.54 | 80,446.19 | 66,159.63 | 346,444.01 | 171,730.96 |
| **Per cent** | 31.99 | 38.55 | 45.95 | 41.97 | 51.31 | 53.21 | 44.21 | 29.21 | 17.58 | 50.84 | 44.17 |
| **No. 4 crude:** [c] | | | | | | | | | | | |
| **Barrels** | | | 42,592.43 | 13,998.10 | | | | | 485.91 | 25,968.07 | 6,942.96 |
| **Per cent** | | | 10.17 | 3.35 | | | | | 0.13 | 3.81 | 1.79 |
| **Total charge:** | | | | | | | | | | | |
| **Barrels** | 607,090.24 | 450,396.73 | 418,662.51 | 417,192.06 | 441,958.60 | 442,109.59 | 303,416.33 | 275,386.41 | 376,295.75 | 681,450.98 | 388,857.11 |
| **Per cent** | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| **Total cubic feet of gas evolved** | 35,162,187 | 23,978,918 | 20,415,778 | 24,997,079 | 28,464,674 | 27,154,890 | 27,956,910 | 26,467,915 | 25,787,399 | 31,399,563 | 21,113,609 |
| **Cubic feet of gas evolved per barrel charged** | 57.9 | 53.2 | 48.7 | 59.9 | 64.4 | 61.4 | 92.1 | 96.1 | 68.5 | 46.1 | 54.3 |
| **Gasoline recovered per 1,000 cubic feet** | 8.962 | 9.033 | 10.062 | 8.291 | 8.188 | 8.499 | 10.621 | 10.904 | 7.438 | 6.692 | 8.501 |
| **Total barrels of gasoline recovered** | 6,302.71 | 4,332.06 | 4,108.44 | 4,144.96 | 4,661.24 | 4,615.93 | 5,940.50 | 5,839.80 | 3,836.70 | 4,202.58 | 3,590.05 |
| **Gallons of gasoline recovered per barrel charged** | 0.519 | 0.481 | 0.482 | 0.496 | 0.527 | 0.522 | 0.978 | 1.060 | 0.509 | 0.308 | 0.462 |

[a] No. 1 crude run for steam-refined cylinder stock, no gas collected after steam was introduced.
[b] No. 1 crude run to coke.
[c] All No. 2 and No. 4 crude run to coke.
[d] All No. 3 crude topped.

NOTE.—Condenser coils cleaned in October; sections of condenser not in use while being cleaned.

TABLE 5.—*General data on plants that recover gasoline from uncondensed still vapors.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Index number. | Nature of refinery. | Nature of crude. | Type of scrubber for removal of sulphur. | Sulphur content. | Type of exhauster and vacuum carried. | Type of recovery plant. | Crude charge, barrels a day. | Gas a day, cubic feet. | Gasoline a day, gallons. | Gasoline recovered per barrel of crude charge, gallons. | Gasoline recovered, per cent of crude charge. |
| 1. | Complete. | Mid-Continent. | Lye. | High. | Rotary exhauster. 4 inches water. | Compression. | 20,000 | 3,500,000 | 14,500 | 0.72 | 1.71 |
| 2. | Complete. | Mid-Continent.<br>Mexican.<br>Pennsylvania. | Lye. | Very high. | Rotary exhauster. 1 inch water. | Compression and absorption of residue. | 13,246 | 1,382,977 | 11,203 | .84 | 2.00 |
| 3. | Complete. | Mexican.<br>Mid-Continent.<br>Pennsylvania. | None. | Very high. | Rotary exhauster. 6 inches to 8 inches water. | Absorption in gas oil. | 25,000 | 5,000,000 | 12,000 | .48 | 1.14 |
| 4. | Complete. | Mexican.<br>Mid-Continent.<br>Pennsylvania. | Iron oxide. | Very high. | Rotary exhauster. 2 inches water. | Compression and absorption of residue. | 40,000 | 2,560,000 | 14,100 | .35 | .83 |
| 5. | Complete. | Mid-Continent.<br>Illinois.<br>Ohio. | Lye. | High. | Rotary exhauster. 3 inches water. | Absorption in 50 naphtha. | 40,000 | 5,600,000 | 16,000 | .40 | .95 |
| 6. | Skimming and lubricating. | Mid-Continent. | None. | Low. | Intake on compressor. 1 inch water. | Compression. | 10,000 | 700,000 | 4,200 | .42 | 1.00 |
| 7. | Skimming and lubricating. | Mid-Continent. | None. | Low. | Intake on compressor. 1 inch water. | Compression. | 4,240 | 350,000 | 2,789 | .65 | 1.55 |
| 8. | Complete but no asphalt or coke. | Wyoming. | None. | Low. | Rotary exhauster. 1½ inches water. | Absorption in 50 naphtha. | 30,000 | 875,000 | 7,859 | .26 | .62 |
| 9. | Complete. | Mid-Continent. | None. | Low. | Rotary exhauster. 1 inch water. | Absorption in gas oil then to pressure still. | 12,000 | (a) | 8,000 | .67 | 1.59 |

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| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | Complete. | Electra.<br>Ranger.<br>Healdton. | None. | Low—no sour gas treated. | Intake on compressor. 2 inches water. | Compression and absorption of residue. | 38,000 | (a) | 5,000 | .13 | .31 |
| 11. | Complete. | Gulf Coast.<br>North Texas.<br>Louisiana-Mexican. | None. | Varies with crude. | Intake on compressor. 2 inches water. | Compression and absorption of residue. | 55,000 | (a) | 10,000 | .18 | .43 |
| 12. | Complete. | Oklahoma.<br>North Texas. | None. | Rather high. | Rotary exhauster. 2 inches water. | Compression and absorption of residue. | 33,000 | 6,331,000 | 21,000 | .63 | 1.50 |
| 13. | Complete. | Mexican-Louisiana.<br>North Texas.<br>Gulf Coast. | Water scrubber. | High. | Rotary exhauster. 3 inches water vacuum. | Absorption in horizontal absorber. | 35,000 | 4,000,000 | 2,000 | .05 | .12 |
| | | | | | | | 355,486 | ........... | 128,651 | Av. 0.444 | Av. 1.05 |

[a] No data on gas volumes.

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## SURVEY OF PLANTS WITH RECOVERY SYSTEMS.

Table 5 shows representative refineries on the Atlantic coast, the Gulf coast, and in Oklahoma, Wyoming, and Kansas that have installed plants for the recovery of gasoline from uncondensed still vapors. Column 10 shows that in these plants the recovery of gasoline ranges from 0.05 gallon to 0.84 gallon per barrel of crude charged. In several plants where the recovery is low, the refineries do not have the most efficient type of plant, and in others the refineries are not fully equipped for taking care of all the gases formed.

In some of the refineries included in the table, the low recovery value is due to the low gasoline content of the crude and to the absence of pressure stills. Other refineries included have pressure stills but the cracked gases are not utilized because of lack of equipment for removing the large content of sulphur compounds.

The figures on crude charge, volume of gas, and gasoline recovered are average figures, and vary greatly from time to time. The greatest errors are probably in the figures for gas volumes, for a number of these have been calculated from compressor displacement.

The total crude oil charged to the refineries as listed in this table amounts to 355,486 barrels per day. By the use of the recovery system for the uncondensed still vapors a total daily gasoline yield of 128,651 gallons is obtained, an average recovery of 1.05 per cent or 0.444 gallon of gasoline for every barrel of crude oil charged. Unless the recovery system was used, this gasoline would be lost or be burned as fuel under the stills and boilers.

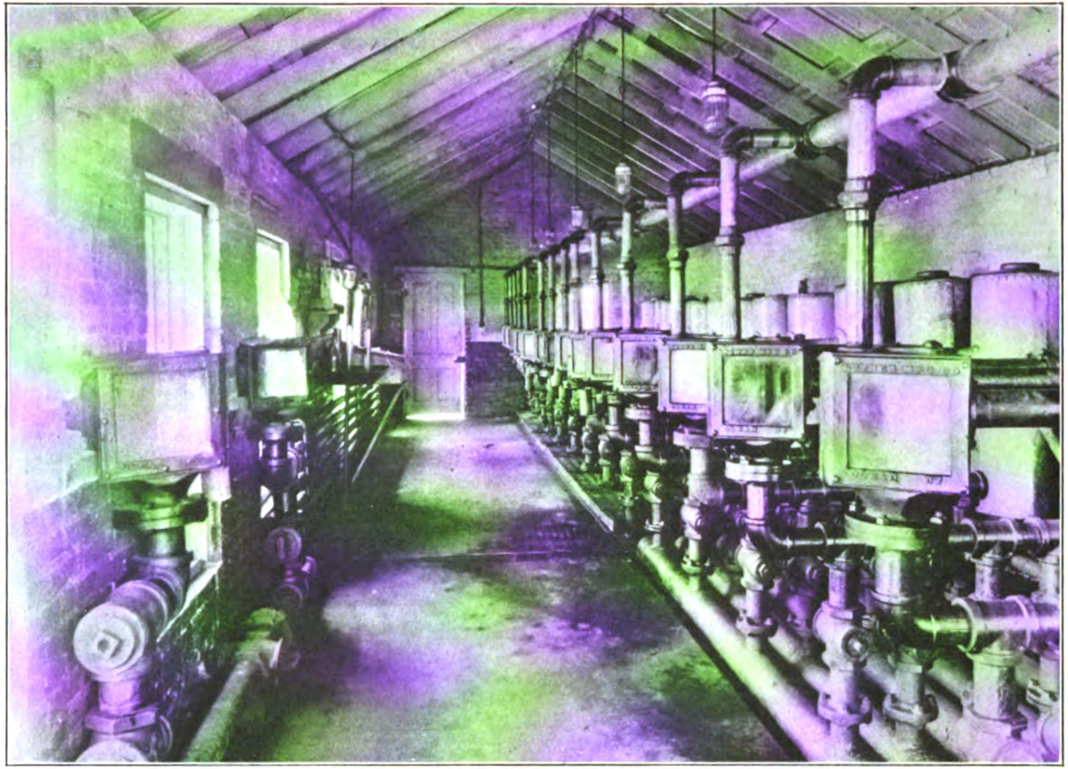
## COLLECTION OF UNCONDENSED VAPORS.

### REMOVAL FROM RUN-DOWN LINES.

In the distillation of crude petroleum the first vapors or gases driven off are naturally the lightest and have the highest vapor pressure of all the hydrocarbons present in the crude. In order to condense these vapors it is necessary for the cooling surface of the condenser coils to be large and held at a low temperature.

Under these conditions all of the vapors would condense except the very lightest, which might properly be called permanent gas rather than gasoline vapor. Almost all of the small amount of gas left uncondensed would be almost dissolved in the condensate. Ordinarily, however, the temperatures of the condenser boxes are so high that a large part of the first few per cent distilled remains uncondensed. By removing these vapors as rapidly as they are formed, and by submitting them to subsequent compression and cooling, or by dissolving them in a low-gravity oil, a large part of the vapors can be recovered as gasoline.

Vapors can be removed from the run-down lines at any point after they have received the maximum cooling effect of the condensers. In some plants they are taken from the bottom of the coil by a riser passing upward through the water in the condenser box (Plate I, *C*,



SOUTHERN OIL CORPORATION, YALE, OKLA., TAIL HOUSE WHERE STREAMS FROM CONDENSERS ARE DIVERTED TO PROPER STORAGE TANKS.

p. 4). This is less desirable than where the gas is taken off outside the condenser box, which cuts down repair costs. More frequently, however, the gases are removed from the run-down lines at the "tail house." Usually a gooseneck or trap is placed between the gas-gathering line and the "look box" to prevent air from being drawn into the line from leaks in the latter. At many of the plants a small vapor line leads from the look box to the gathering line, although in most of them the line from the look box discharges directly into the atmosphere, because only a little gas comes from the look box, and any leakage in the look box would result in this small volume of gas being diluted with air. This arrangement is illustrated in Figure 4 and Plate IV.

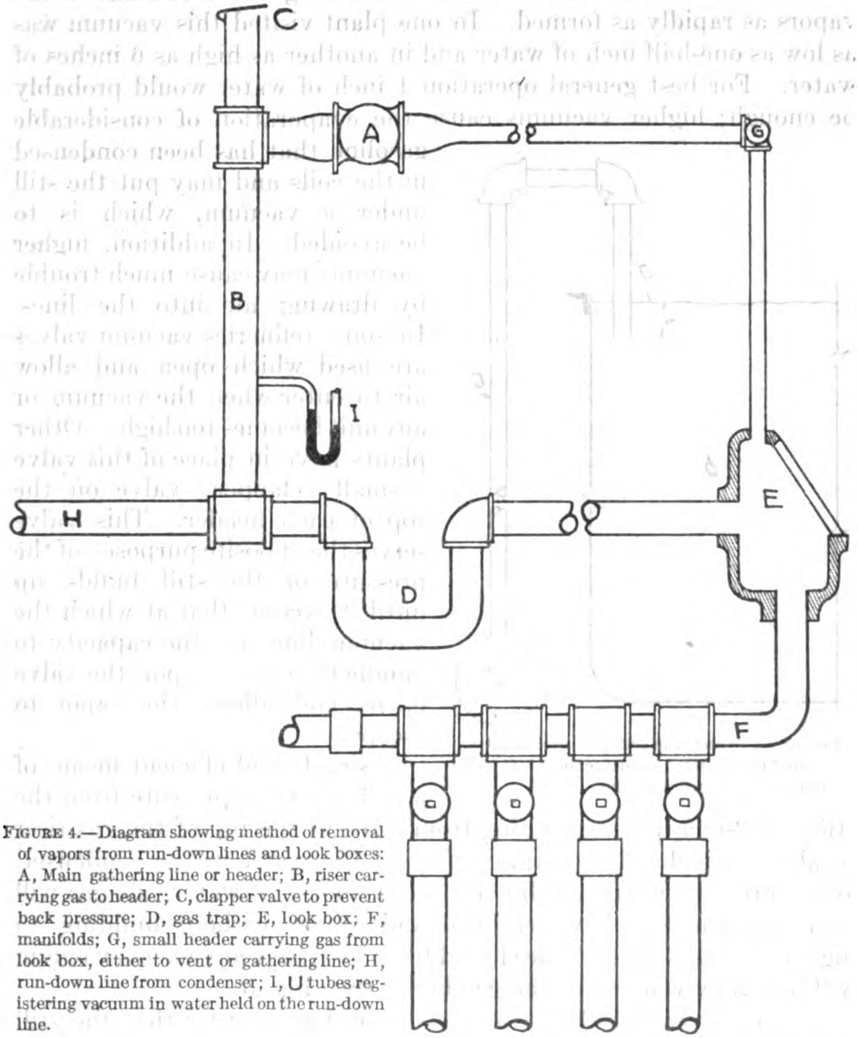


FIGURE 4.—Diagram showing method of removal of vapors from run-down lines and look boxes: A, Main gathering line or header; B, riser carrying gas to header; C, clapper valve to prevent back pressure; D, gas trap; E, look box; F, manifolds; G, small header carrying gas from look box, either to vent or gathering line; H, run-down line from condenser; I, U tubes registering vacuum in water held on the run-down line.

The risers from the bottom of the worm or from the gooseneck differ in diameter with the volume of gas they are expected to handle; they generally are not less than 1¼ inches and range up to 3 inches. In a large plant with several tail houses the small risers enter a larger line, which in turn discharges into a still larger main line that leads through the trap to the gas plant.

A vacuum is held on these lines and is regulated to remove the vapors as rapidly as formed. In one plant visited this vacuum was as low as one-half inch of water and in another as high as 6 inches of water. For best general operation 1 inch of water would probably be enough; higher vacuums cause the evaporation of considerable gasoline that has been condensed in the coils and may put the still under a vacuum, which is to be avoided. In addition, higher vacuums may cause much trouble by drawing air into the lines. In some refineries vacuum valves are used which open and allow air to enter when the vacuum or any unit becomes too high. Other plants have in place of this valve a small "clapper" valve on the top of each header. This valve serves the opposite purpose—if the pressure of the still builds up until it exceeds that at which the vacuum line has the capacity to handle the excess vapor, the valve opens and allows the vapor to escape.

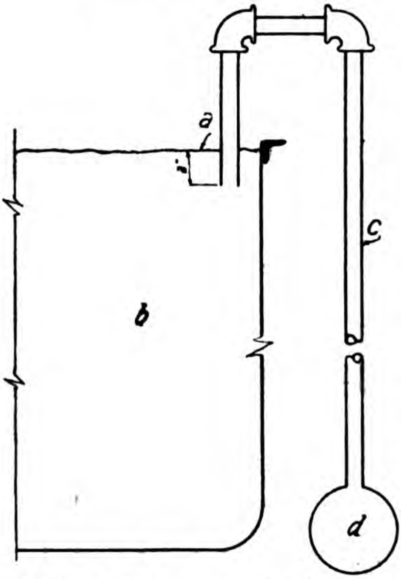


FIGURE 5.—Water trap acting as a relief valve: *a*, Surface of water; *b*, condenser box; *c*, 1½-inch line; *d*, 8-inch gathering line.

A simple and efficient means of avoiding excess pressure from the still is a 2-inch pipe extending from a tee at the top of the gas riser to about 2 inches below the surface of the water in the condenser. When pressure in the gas line exceeds 2 inches of water, the gas will overcome the 2-inch water head and relieve without building up higher pressure. This pipe should be so long that any excess vacuum will not draw water into the gas line. (See Fig. 5.)

A combination of these valves is desirable in order that the still may never be under too much pressure or vacuum from the gas system.

At most recovery plants care in eliminating air will do more to increase efficiency than attention to any other detail. Addition of air to the gas not only increases the volume to be handled but makes

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BUREAU OF MINES TECHNICAL PAPER 310 PLATE V

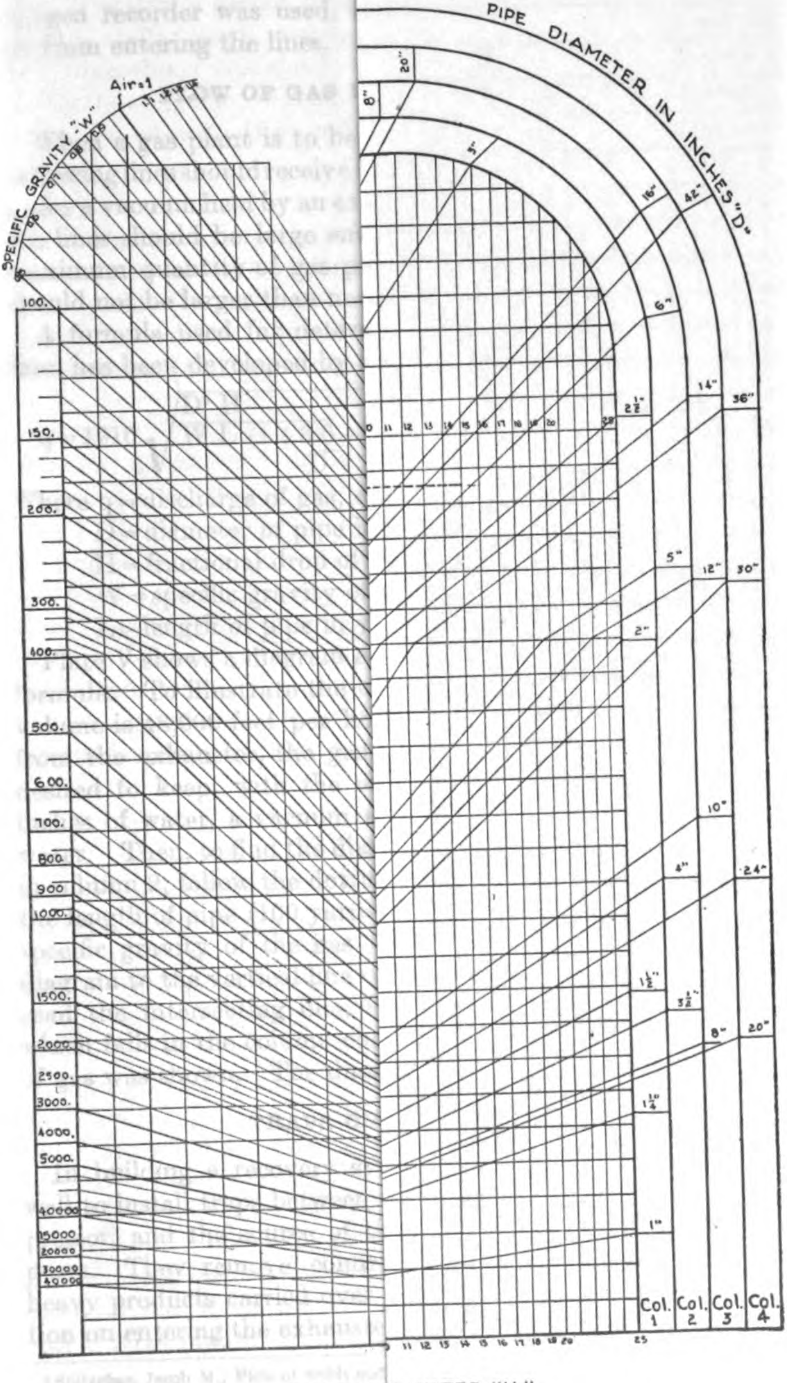

CHART FO F WATER "H."

the recovery of gasoline more difficult. In one plant visited an oxygen recorder was used, and every effort was made to prevent air from entering the lines.

## FLOW OF GAS IN LOW-PRESSURE LINES.

When a gas plant is to be erected at a refinery, the design of the gathering lines should receive special attention. As the gas is gathered under a vacuum held by an exhauster or by the intake of a compressor, the lines should be large enough to handle under the vacuum the maximum quantity of gas produced, yet, on account of extra cost, should not be larger than necessary.

A formula used for determining the flow of gas in low-pressure lines has been developed by Spitzglass:[3]

$$q = 1910\sqrt{\frac{D^5 H}{W L \left(1 + \frac{3.6}{D} + .03D\right)}}$$

Where q = discharge of gas, cubic feet per hour,
D = diameter of pipe in inches,
H = fractional drop of pressure, inches of water,
W = specific gravity of gas (air = 1), and
L = length of pipe in yards.

Plate V shows a diagram computed by Mr. Spitzglass to cover this formula. To illustrate the use of this diagram, assume that the gas volume is 48,000 feet per hour, the source of the gas is 100 yards from the exhauster, the gas has a specific gravity of 1.1, and it is desired to keep, with the exhauster maintaining a vacuum of 20 inches of water, a vacuum at the source of the gas of 5 inches of water. Then, to find the diameter of pipe required, start with 48,000 in column 2, follow the dotted line horizontally to the line indicating the length of pipe (100 yards), vertically to the line representing the specific gravity of the gas (1.1), and then horizontally across the diagram to the vertical line representing drop in pressure (15 inches); read the intersecting line, representing the diameter of the pipe, which falls in the column corresponding to that in which the volume of gas was shown. The diameter of the pipe required is 6 inches.

## TRAPS ON GATHERING LINES.

In building a recovery system for uncondensed still vapors it is well to install traps between the exhauster, or the intake of the compressor, and the source of the gas. These traps serve several purposes. They remove condensate caused by air cooling and any heavy products carried over mechanically which would ruin lubrication on entering the exhauster or compressor; they equalize pressure, preventing sharp changes of pressure in the run-down lines, and serve to remove sulphur compounds. Plate VI, *A*, shows a trap with connections to the gas risers from the run-down lines. Plate VI, *B*, shows a gas line with a drip or leg that collects any condensate that may have been formed in the lines by aerial cooling, and if not removed would be carried as liquid gasoline to the compressor.

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[3] Spitzglass, Jacob M., Flow of fluids and frictional resistance in pipes: Armour Engineer, March and May, 1917.

### FORM OF TRAPS.

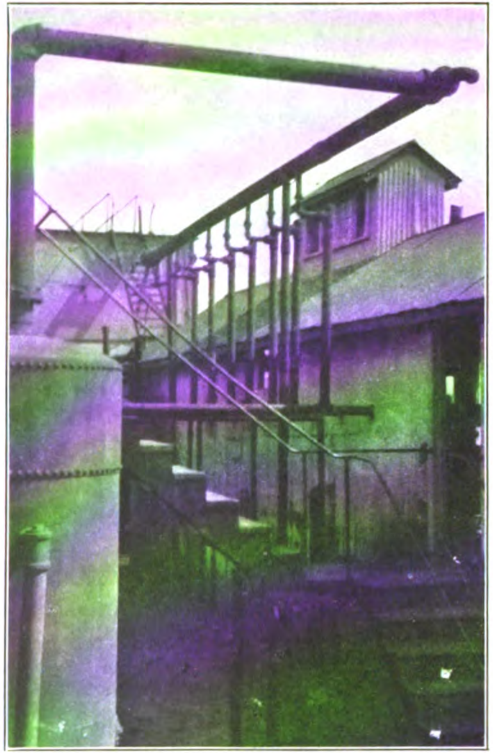
In the different refineries visited these traps were practically of the same type, consisting of a steel tank from about 4 feet in diameter by 5 feet high to 15 feet in diameter by 18 feet high. In these traps the gas receives a preliminary washing with water, which removes sulphur, any naphtha that may have been condensed, and any heavier hydrocarbons carried over mechanically.

Various devices for washing are used. The simplest is a gas inlet line entering below the water level. The more complex have inside the inlet pipe a small water line with drilled holes, which sprays the gas before it passes through the water seal.

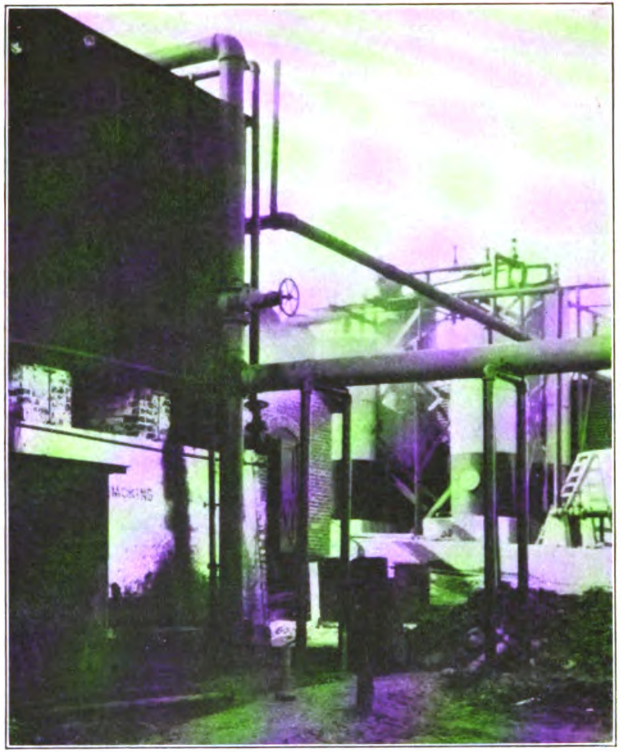
At some plants traps are placed in every "tail" house, and at others one large trap is installed in the exhauster house. At one refinery visited, where a trap was installed at each unit, a steel tank 15 by 18 feet is used. A 12-inch gas intake line enters the top and drops to within 3 feet of the bottom; the gas, after being washed by a spray, bubbles upward through the water. The washed gas leaves the trap at the top through a line that goes directly to an exhauster. Figure 6 shows a diagram of this trap.

### VALVES ON TRAPS.

The trap previously described has a relief valve, which prevents trouble at the still by venting gas into the air when excessive pressure builds up in the lines. A butterfly valve (Fig. 6), regulated from time to time to hold the same vacuum on the run-down lines, is also used. Devices of this sort are necessary because of the wide variations in volume of the gas from the condenser coils. If the vacuum carried on the trap is not sufficient to handle the vapors as rapidly as they form, a back pressure builds up on the still. This condition should be avoided. The volume of the gas varies with the temperature of water, differences in the crude, and other factors. If the vacuum carried on the lines is too high to be compensated by the gas formed, a vacuum is exerted directly on the still. This condition also should be avoided. The vacuum carried on the lines should be just enough to take care of the vapors, no more and no less. Then the same pressure conditions will prevail as would exist if the uncondensed still vapors passed directly into the air.

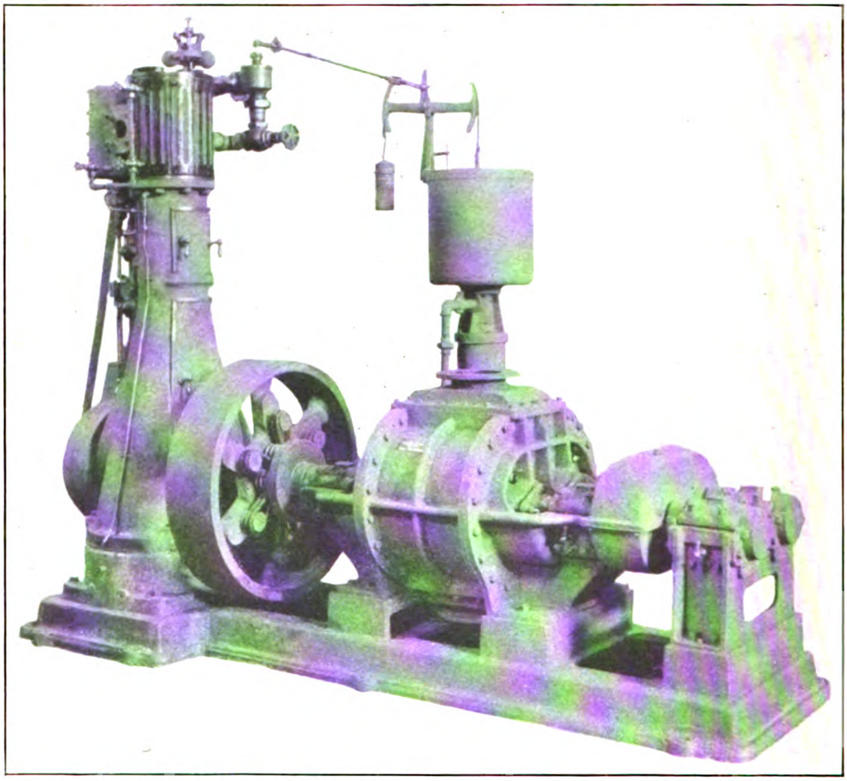


*A.*—TRAP RECEIVING GAS FROM HEADER ON RUN-DOWN LINE.



*B.*—GAS LINE WITH LEG FOR COLLECTION OF CONDENSED WATER AND GASOLINE.

Original from PRINCETON UNIVERSITY



SMALL EXHAUSTER AND STEAM ENGINE.

In some plants the lighter petroleum fractions condensed in these traps are allowed to waste into the sewer. In others the condensed naphtha is removed from the surface of the water with a skimmer and subsequently recovered as gasoline.

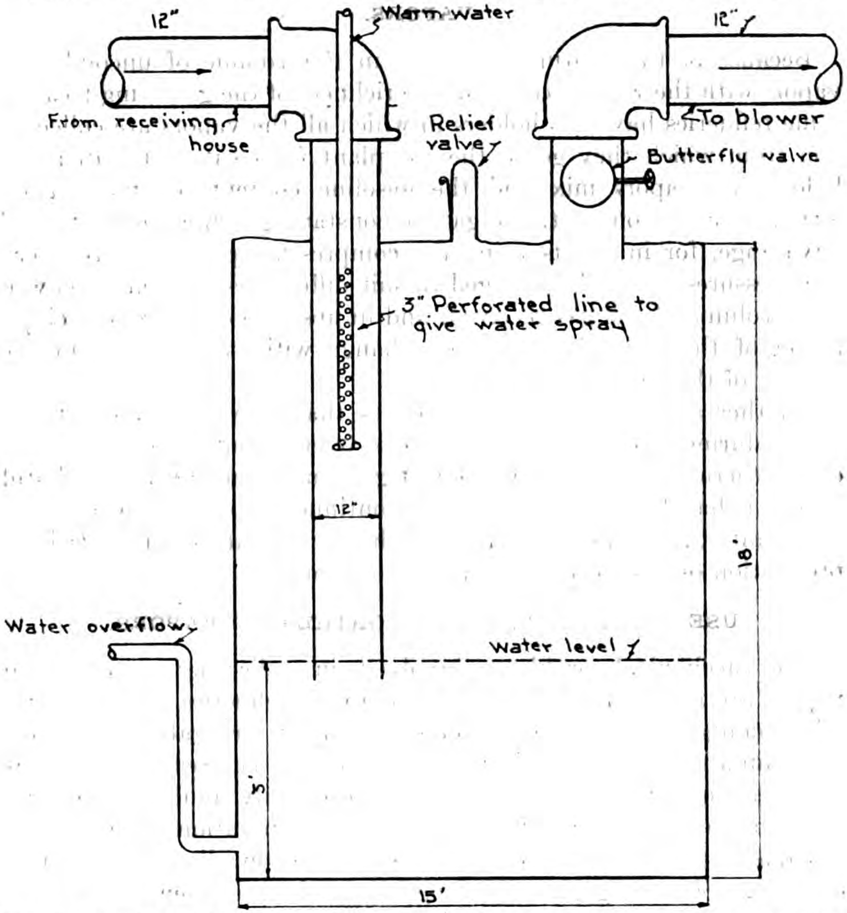


FIGURE 6.—Type of trap that washes gas; it has a relief valve for excess pressure and a butterfly valve to prevent excess vacuum.

## TRAPS FOR COOLING ONLY.

In one plant, where sulphur compounds were not troublesome, the traps were used chiefly for cooling the gas. The vapors were taken from the bottom of the worm through a riser which was inside the condenser box. In passing upward through the warm water at the surface of the condenser box the vapors became heated, and they were cooled before they entered the absorption towers, because much better absorption is obtained at lower temperatures.

Original from PRINCETON UNIVERSITY

In still other refineries no water washing is done; the traps are used solely to collect condensate precipitated in the lines by air cooling, and thus keep the compressors free from condensed gasoline.

## USE OF GAS HOLDER IN COLLECTING UNCONDENSED STILL VAPORS.

Because of the continual changes in the volume of uncondensed vapors with the wide variance in the richness of the gas being treated, some refineries have gas holders in which all the vapors are collected and from which they go to the gas plant for treatment. In a gas holder the vapors mix and the gasoline content of the mixture becomes quite constant. A gas of constant gasoline content is of advantage, for in plants using the compression process of recovery the pressures should be changed to suit differences in quality as well as in volume of the gas received, and in absorption plants the circulation of the absorbing oil must change with the changes in the quality of the gas.

Another advantage of gas holders is that they permit gas to be stored during short shutdowns of the recovery plant. In small refineries, where the total production of gasoline from uncondensed still vapors is hardly enough to warrant continuous operation of a recovery plant, the installation of a gas holder would permit a 24-hour production of gas to be treated in a few hours.

## USE OF EXHAUSTERS FOR GATHERING VAPORS.

The mechanical problems involved in collecting uncondensed vapors are much more complex at complete refineries than in skimming plants, for at these uncondensed vapors are gathered from a small number of crude stills and steam stills. The recovery systems installed in complete refineries are necessarily much larger and much more complicated, because the wide separation of sources of gas makes the carrying of the same vacuum on all run-down lines difficult. Skimming plants taking crude charges even larger than those taken by complete refineries have a smaller number of stills, and hence shorter and less complicated gathering lines. In a skimming plant of this type an exhauster is not necessary, as the vacuum needed for gathering the vapors can be developed by the intake of the compressor.

In complete refineries, however, where pressure stills, lubricating stills, rerun stills, steam stills, and crude stills are all used, the area of the plant is much larger, the gases formed differ greatly in composition and volume, the pressures vary over wide limits, and the gathering lines are more complex and much longer. Hence the installations made must permit the gathering of different gases and yet not permit pressure to build up in any still that is generating a large amount of gas nor a vacuum to come on a still that is making very little gas.

## ADVANTAGES GAINED BY USE OF EXHAUSTERS.

Positive-pressure rotary blowers or exhausters, such as shown in Plate VII, are used for gathering uncondensed vapors. They can handle large volumes of gas, hold the run-down lines under a vacuum of 1 to 4 inches of water, and discharge at a pressure high enough to force the gas through the sulphur scrubbers. Reciprocating machines and fans are not recommended for this work.

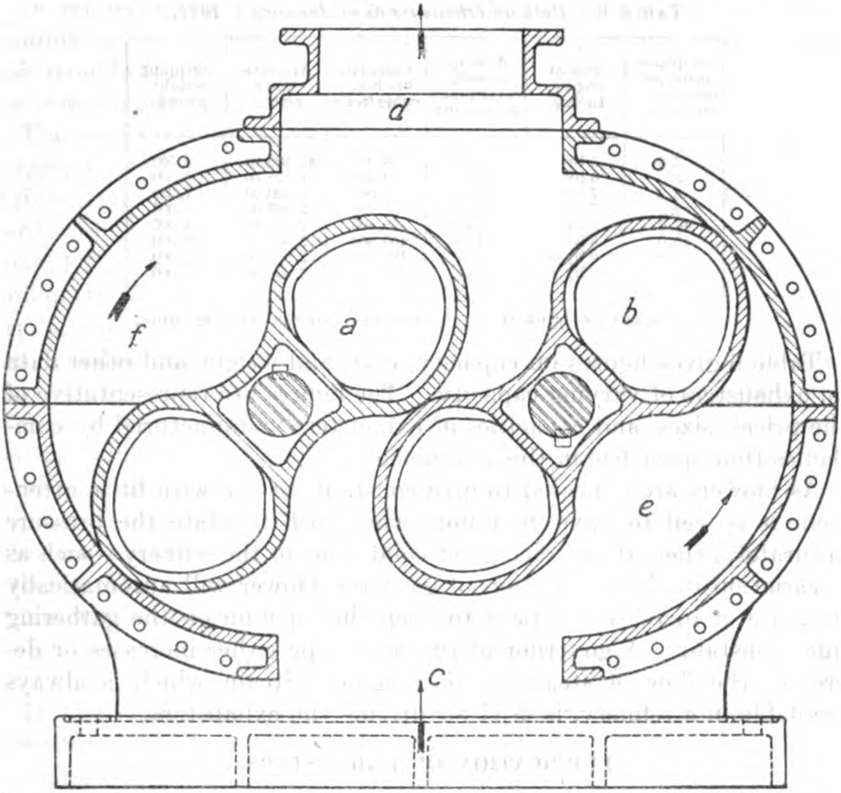


**Figure 7.**—Section through exhauster, showing arrangement of impellers: *a*, *b*, Impellers; *c*, inlet *d*, discharge; *e*, *f*, course of gas.

## CONSTRUCTION OF EXHAUSTERS.

Figure 7 shows a cross section of a rotary exhauster. The two impellers are cast in single pieces reinforced within to prevent warping and are designed with accurately gauged clearances. They are balanced for all speeds and are mounted on parallel shafts. Timing gears maintain the same relation between the impellers, which rotate in opposite directions. The intake gas at *c* enters the space *e* between impeller *b* and the wall of the exhauster. As the impeller turns the tip cuts off the opening to the suction side and the opposite tip forces the trapped gas out through discharge *d*. This action takes place twice with each revolution of the impeller, or four times for each revolution of the exhauster. Extra heavy flywheels are an advantage in maintaining a uniform motion at the slow speeds at which exhausters frequently have to run.

TABLE 6.—*Data on exhausters as of January 1, 1921.*

| Displacement per revolution, cubic feet. | Size of engine, inches. | Average speed, revolutions per minute. | Capacity per hour, cubic feet.[a] | Approximate price.[b] | Shipping weight, pounds. |
|---|---|---|---|---|---|
| 3.0 | 5 by 7 | 170 | 23,940 | $1,400.00 | 4,500 |
| 5.5 | 6 by 7 | 155 | 39,200 | 1,525.00 | 6,500 |
| 8.2 | 7 by 7 | 145 | 55,000 | 1,800.00 | 7,250 |
| 9.0 | 7 by 7 | 135 | 56,700 | 2,000.00 | 8,000 |
| 13.0 | 8 by 8 | 135 | 93,600 | 2,250.00 | 9,000 |
| 15.0 | 8 by 8 | 125 | 100,900 | 2,500.00 | 10,000 |
| 19.0 | 9 by 9 | 125 | 127,200 | 2,900.00 | 12,000 |
| 22.0 | 9 by 9 | 115 | 136,900 | 3,025.00 | 13,000 |

[a] Allowance for shrinkage.
[b] Includes engine as well as governor.

Table 6 gives figures on capacity, cost, and weight and other data on exhausters of varying capacity. The figures are representative of the prices, sizes, and capacities of exhausters manufactured by companies that specialize in this equipment.

As blowers are expected to give constant service with little attention, it is well to have governors which will regulate the pressure accurately; then at any change of conditions in the refinery—such as a variation in the production of gas—the blower will automatically decrease or increase its speed to keep the vacuum on the gathering lines constant. A governor of the float type either increases or decreases the flow of steam to the engine. Steam, which is always available in a refinery, is used for driving the exhausters.

## LUBRICATION OF EXHAUSTERS.

In one refinery visited two exhausters with a daily capacity of 2,500,000 feet of gas were in use. A series of operating tests of different methods of lubrication showed that best results were obtained by feeding a half gallon of 50 to 54° naphtha into the exhauster in a half hour, followed by feeding lubricating oil for about 5½ hours; in a 24-hour run 2 gallons of naphtha and 2 quarts of lubricating oil were used. The lubricating oil had the following characteristics:

*Characteristics of lubricating oil.*

| | | |
|---|---|---|
| Gravity | °B. | 23.8 |
| Flash point | °F. | 420 |
| Cold test | °F. | 32 |
| Viscosity at 70° F | | 410 |
| Viscosity at 100° F | | 307 |

No trouble with lubrication was ever experienced. In eight years' time there had been only one forced shutdown, which was due to an accumulation of sulphur in the walls of the blower. It is now the practice to take the blowers apart once a year and clean out any deposited sulphur.

## REMOVAL OF SULPHUR FROM UNCONDENSED STILL VAPORS.

### SULPHUR IN PETROLEUM.

In refineries that use cracking stills the presence of sulphur compounds in the vapors gives much trouble. Skimming plants have less trouble from sulphur, and consequently do not have to provide for removing it from the uncondensed still vapors.

The magnitude of the problem of sulphur removal is determined largely by the nature of the crude, for different crudes have a widely different sulphur content. Some Mexican crude runs as high as 5 per cent sulphur; California crudes range from 0.34 per cent to 3.55 per cent; 1.75 per cent is typical for Gulf coast crudes, whereas Oklahoma and north Texas crudes carry about 0.4 per cent, except Healdton crude, which has only 0.76 per cent. Pennsylvania crude is exceedingly low in sulphur, only about 0.06 per cent, whereas Lima, Ohio, crude carries 0.65 per cent. Canadian crude runs as high as 1 per cent.

This sulphur is present in the crude partly as free sulphur and partly combined with hydrocarbons, which, according to Mabery,[4] have the general empirical formula of $C_nH_{2n}S$. The compound $C_{10}H_{20}S$ is representative of this class. These compounds proved "unstable when heated in contact with air, but distilled without decomposition in vacuum. This structure is uncertain, but probably cyclic with sulphur, the connecting link."

### DECOMPOSITION OF SULPHUR COMPOUNDS.

In the fractional distillation of crude oil the temperatures and pressures used do not break down these sulphur compounds enough to cause the deposition of much free sulphur in the lines carrying the vapors to the gas house; generally the sulphur compounds are dissolved in the distillates and are removed by chemical treatment. Those sulphur compounds that remain in the vapors are not ordinarily considered of enough importance to warrant the installation of scrubbers. In refineries where pressure stills are used or where crudes of rather high sulphur content are refined, however, the temperatures and pressures are such that these organic sulphur compounds are broken down more completely. A result is the probable formation of hydrogen sulphide, which in turn is readily oxidized to sulphur and water, or at high temperatures breaks down to hydrogen and free sulphur. That decomposition of sulphur compounds takes place is evidenced by deposits of free sulphur on look boxes and by sulphur dust which, if not removed, fills up the lines, blowers, and valves of the gas plant. The writer has seen a 2-inch cast-iron T as completely filled with sulphur as it would have been had the sulphur been melted and poured in.

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[4] Mabery, Charles F., Elements that compose petroleum: Oil and Gas Jour., vol. 19, Sept. 10, 1920, p. 68.

As stated before, the character of the crude determines the amount of sulphur in the vapors. In several refineries where varying amounts of Mexican crude are handled the sulphur content of the uncondensed vapors ranges between 600 and 3,000 grains of sulphur per 100 cubic feet of gas.

### USE OF LYE SCRUBBERS.

Several methods have been used for removing sulphur from uncondensed still vapors. The one that probably is in widest use is scrubbing the gas with a lye solution after its discharge from the exhauster. In this method the gas is passed countercurrent through a series of scrubbers filled with wooden baffles. Water scrubbers remove the free sulphur and dissolve some of the hydrogen sulphide; then the gas passes into a lye scrubber, which contains a solution of caustic soda made up to 15° B. (1.115 sp. gr.), where the hydrogen sulphide and other sulphur compounds are removed. A final water scrubber removes any alkali that might be carried over from the lye scrubber.

A plant on the Atlantic seaboard using this system has six tower scrubbers 20 feet high and 4 feet in diameter connected in series as shown in Figure 8. These scrubbers are filled with wooden baffling of 1-inch by 6-inch boards, supported by an angle iron riveted inside the tower. The gas enters each scrubber 2 feet from the bottom and passes up countercurrent to warm salt water (about 5° warmer than the gas) pumped directly from the condensers. The higher temperature of the water serves to keep any of the gasoline in the vapor from condensing. The water used is salt because it is sea water which is available in unlimited quantities. Its salinity is of no advantage, in fact the sodium and magnesium compounds promote corrosion and are detrimental to the steel in the towers.

The gas is taken from a line 4 inches from the top of the scrubber and enters the next in series 2 feet from the bottom, passes through four of these water scrubbers, and then into a lye scrubber. From this tower the gas passes into the sixth and last scrubber where warm sea water washes the vapors and removes any lye carried over mechanically. The water and lye are circulated by duplex pumps, the lye being recirculated until the absorbing efficiency is lowered to the point where fresh lye is required. The source of the crude again becomes a factor since, according to the men operating the plants, lye does not absorb sulphur from the vapors of Mexican crude as readily as it does from Mid-Continent crude.

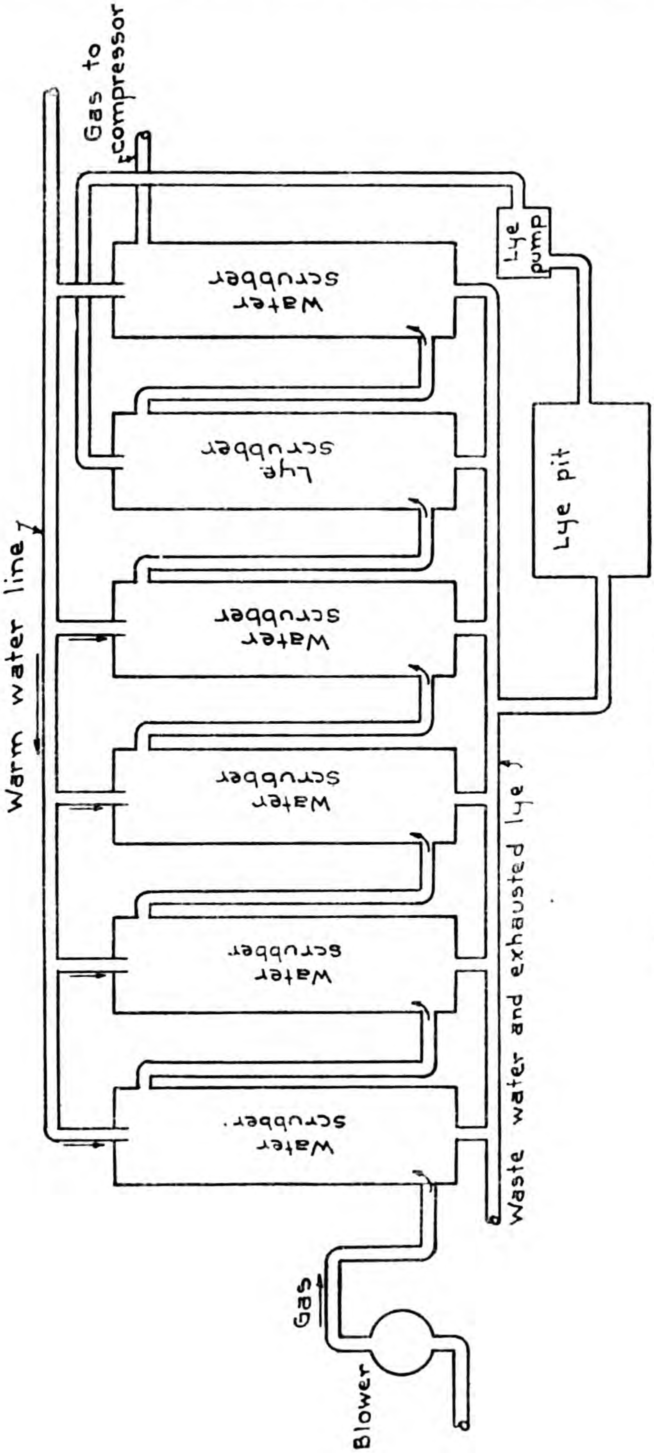

FIGURE 8.—Flow sheet of lye treatment for removal of sulphur.

### CHEMICALS REQUIRED.

In this plant twelve 600-pound drums of sodium hydroxide (lye) made up with water to 15° B. treats 1,500,000 cubic feet of vapor a day and lasts 3 to 4 weeks. The crude refined is 20 per cent Mexican of 22° B., 60 per cent Mid-Continent of 33.4° B., and 20 per cent Pennsylvania crude of 41.5° B. A fresh solution of lye lowers the sulphur content from about 3,000 grains per 100 feet of gas to about 60 grains per 100 cubic feet, but this efficiency drops rather rapidly. Blowing the lye with air revivifies the charge and greatly increases the life of the solution.

TABLE 7.—*Results of scrubbing gas with lye.*

| Hours. | Sulphur per 100 cubic feet before scrubbing. | Sulphur per 100 cubic feet after scrubbing. |
|---|---|---|
| | *Grains.* | *Grains.* |
| 1 | 1,260 | 60 |
| 28 | 1,260 | 150 |
| 48 | 1,920 | 900 |
| 51 | 1,530 | 1,200 |
| 69 | 1,380 | 1,110 |
| 93 | 930 | 690 |
| 99 | 870 | 810 |
| 117 | 750 | 450 |
| 123 | 1,470 | 1,140 |
| 141 | 1,110 | 1,020 |
| 147 | 1,320 | 1,260 |

In order to determine the efficiency of the lye treatment, gas with a very high sulphur content was treated with fresh lye of 13° B. The results of this test are given in Table 7. These results show that the sulphur content of the gas varied widely in the experimental test and that sometimes was very much higher than in the ordinary operation of this plant; which in consequence used up the lye more rapidly than usual.

The cost of this treatment is not excessive, as sodium hydroxide costs about $4 per 100 pounds. The spent lye is carried away by the sewers.

### REMOVAL OF SULPHUR BY THE IRON OXIDE METHOD.

A second method of removing sulphur from the gas is by the use of iron oxide. This method is not employed as widely as the lye method, but certain advantages are bringing it into more general use. The gas is scrubbed with iron oxide suspended in water by agitation with air; the sulphur is removed from the gas and is changed to an iron sulphide. The air not only keeps the iron oxide in suspension, but helps to revivify it by supplying air for converting iron sulphides to iron oxides.

### EXPERIMENTAL RESULTS.

Experimental work on this method of purification has been done by Mr. Lester M. Goldsmith,[5] of the Atlantic Refining Co., at Philadelphia, Pa.

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[5] Goldsmith, Lester M., Liquid purification of gases: Gas Age, Feb. 25, 1920, vol. 45, pp. 161-165.

Mr. Goldsmith tried the use of water alone, water containing iron oxide, and water containing lime in suspension. Results of his work are shown in Table 8.

TABLE 8.—*Gas purification by suspended oxides.*

(Determined by Lester M. Goldsmith.)

| Test No. | Material in suspension. | Length of runs, hours. | Gas per hour, cubic feet. | Total gas passed, cubic feet. | Total air used for revivification in tower, cubic feet. | Total air used for revivification and agitation in tanks, cubic feet. | Rate of liquid flow per minute, gallons. | Sulphur content of gas per 100 cubic feet, grains. | Total sulphur in gas, grains. | Total sulphur extracted, grains. | Extraction, per cent. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Water** | 6 | 6,800 | 40,800 | 98,000 | 96,000 | 110 | 800 | 326,400 | 163,200 | 50.0 |
| 2 | 3 per cent $Fe_2O_3$ | 32 | 4,600 | 147,130 | 537,000 | 500,000 | 85 | 1,490 | 2,185,000 | 1,654,000 | 85.0 |
| 3 | .....do | 36 | 5,350 | 192,000 | ........ | 770,000 | 110 | 750 | 1,440,000 | 1,200,000 | 84.6 |
| 4 | 5 per cent $Fe_2O_3$ | 62 | 5,150 | 320,000 | ........ | 1,750,000 | 110 | 855 | 2,740,000 | 2,260,000 | 82.5 |
| 5 | 3 per cent $Ca(OH)_2$ | 36.5 | 3,730 | 136,000 | ........ | 510,000 | 110 | 1,590 | 2,160,000 | 1,733,000 | 80.3 |
| 6 | 3 per cent $Fe_2O_3$ | 50 | 3,450 | 172,000 | ........ | 615,000 | 110 | 1,850 | 3,200,000 | 3,043,000 | 95.0 |
| 7 | .....do | 60 | 4,000 | 240,000 | ........ | 920,000 | 70 | 2,100 | 5,060,000 | 4,737,000 | 93.5 |
| 8 | .....do | 17 | 4,120 | 70,000 | ........ | 65,000 | 85 | 650 | 453,600 | 370,300 | 81.5 |
| 9 | .....do | 22 | 4,090 | 90,000 | ........ | 185,000 | 85 | 710 | 693,000 | 511,200 | 80.0 |
| 10 | .....do | 13 | 2,000 | 26,000 | 286,000 | 26,000 | 85 | 2,600 | 678,600 | 566,000 | 83.5 |

This purification plant had two towers of steel, 20 inches in diameter and 20 feet high, filled with spiral tile as baffling. One tower was a scrubber for the gas, which passed upward countercurrent to a stream of suspended iron oxide; the second was a revivifying tower in which the fluid from the first tower passed down countercurrent to a stream of air. Two tanks were placed below these towers for storing the iron oxide being circulated.

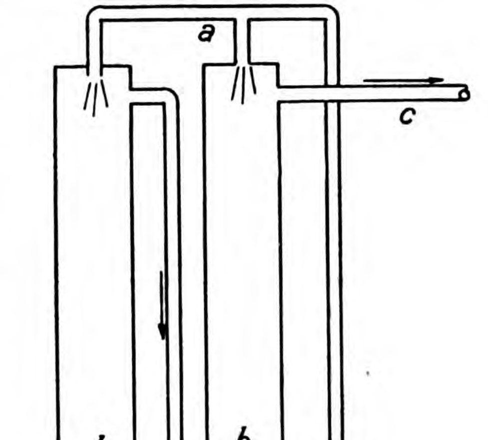

FIGURE 9.—Flow sheet of iron-oxide treatment for removal of sulphur: *a*, Suspended iron oxide; *b*, oxide scrubbers; *c*, gas to compressor; *d*, iron-oxide pump; *e*, untreated gas; *f*, iron-oxide tank; *g*, air pump to agitate iron oxide.

Table 8 shows that in test No. 1 where water alone was used the percentage of extraction was very low. In test No. 5, where lime was used, the extraction was low. As the efficiency of extraction with water was low, and as lime costs more and had lower efficiency than iron oxide, both water and lime suspensions were considered unsatisfactory.

A 3 per cent suspension of iron oxide was made up and tests No. 2 and No. 3 were run. In test No. 3 no air was used for revivification other than that supplied for agitation, whereas in test No. 2 air for revivification was used in the tower. Both tests gave practically the same results. Test No. 4 was then made with a 5 per cent suspension of iron oxide. This concentration was not satisfactory since the oxide settled and plugged the lines. The arrangement of the plant was then changed so that each tower acted as a purifying tower, and revivification was eliminated except in the tanks where air was used for agitation. Test No. 6, made under these conditions, gave the best extraction. Tests Nos. 7, 8, and 9 were made in order to determine the effects of revivification; they demonstrated that a lower proportion of air to gas than that shown in tests Nos. 6 and 7 was insufficient. Test No. 10 verified the earlier conclusion that the revivifying tower was doing practically nothing.

This investigation indicated that 95 per cent of the sulphur could be removed easily, but the removal of all the remainder was very difficult. The tests also showed that it was better and cheaper to provide fresh iron oxide than to attempt revivification in the towers. Figure 9, p. 33, shows a diagram of a plant using iron oxide to remove sulphur from uncondensed still vapors.

Although the above experiments indicated the inefficiency of lime as a purifying agent, several plants in the United States use lime with seemingly satisfactory results. One plant, which treats about 5,000,000 cubic feet of sweet and sour gases a day, uses three scrubbers (14 feet in diameter and 45 feet high), in series through which suspended lime solutions circulate countercurrent to the gas. The lime is mixed in a 6 by 8 foot lime tank in the proportion of 1 pound of lime to 1 gallon of water, and is kept in suspension by a motor-driven agitator. After the lime suspension has circulated through the scrubber for 8 hours, it is pumped to the second scrubber and a new charge is made up for the first. With this system a fresh charge of lime is made and a charge of spent lime is wasted every 8 hours.

The removal of sulphur by introducing ammonia gas to form a sulphide of ammonia has been tried but proved rather unsuccessful.

## METHODS OF RECOVERING GASOLINE FROM UNCONDENSED STILL VAPORS.

The uncondensed still vapors may be treated in several ways to recover the gasoline vapors present: By compression, in which method the vapors are compressed and cooled and the gasoline precipitated as a liquid; by absorption, in which an absorbing oil brought into intimate contact with the vapor selectively absorbs the heavier hydrocarbons from the lighter (permanent gases); or by a combination of the two methods, in which an absorption system treats the residual gas from a compresssion plant.[6]

## PHYSICAL LAWS GOVERNING RECOVERY OF GASOLINE BY COMPRESSION AND ABSORPTION PROCESSES.

In uncondensed still vapors, the boiling point of the gasoline that exists in the vapor state may be much higher than atmospheric temperature. In a liquid the molecular movement depends on the temperature at which the liquid is held, and with any molecular movement a definite amount of evaporation takes place. Gasoline evaporating in a closed vessel will continue to evaporate until the pressure exerted by the gas above the liquid is just enough to balance the vapor tension of the liquid, or the tendency of the liquid to vaporize. Under these conditions a state of equilibrium is said to exist. If this vapor and liquid are cooled a few degrees (the pressure remaining constant) some of the vapor condenses as gasoline, or, if the vapor is held at the same temperature and more pressure applied, some of the vapor condenses to restore the equilibrium.

If a gas that contains a large percentage of gasoline vapor is condensed and the heat formed by compression is removed by means of some cooling agent—in this case water—an equilibrium must be reached, but it can be reached only by the condensation of the gasoline. In practice this process is so regulated by experiment as to maintain pressures and temperatures at which the gasoline is condensed without the precipitation of some of the very volatile hydrocarbons, which have such low boiling points and high vapor pressures that they can not be held as gasoline when the pressure is relieved. No close separation, however, can be made; and in this system of recovering gasoline some of the vapors remain uncondensed, and also some of the lighter hydrocarbons are condensed or are dissolved as gases in the gasoline produced.

The absorption process depends on the solubilities of light hydrocarbon vapors in heavier oils. These solubilities in turn depend largely on the vapor pressures of the light fractions and of the absorbing oil. For example, a very much smaller percentage of methane than of pentane will dissolve in a given oil. Hence, when the gases from the run-down lines are brought into intimate contact with an oil, the heavier hydrocarbons are selectively absorbed and the permanent gases pass on without being dissolved much.

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[6] Dykema, W. P., Recovery of gasoline from natural-gas gasoline by compression and refrigeration: Bull. 151, Bureau of Mines, 1918, 119 pp.; Recent developments in the absorption process for recovering gasoline from natural gas: Bull. 176, Bureau of Mines, 1919, 84 pp.

Dykema, W. P., and Neal, R. O., Absorption as applied to recovery of gasoline left in residual gas from compression plants: Tech. Paper 232, Bureau of Mines, 1920, 40 pp.

In the combination of compression and absorption methods, the discharge gas from the compression plant is washed with 50° B. naphtha. This naphtha is blended with the raw gasoline obtained by compression.

## COMPRESSION PROCESS.

### ADAPTABILITY OF PROCESS TO UNCONDENSED STILL VAPORS.

The compression process is used more widely for recovering gasoline from refinery gases than is the absorption process. As the compression process was first developed for recovering gasoline from casing-head gas, and as uncondensed refinery vapors are much like casing-head gas, its application in the refinery was a natural development.

The compression process is well suited for recovering gasoline from uncondensed still vapors, as the gasoline content is high, and extremely high pressures are not necessary to recover the larger part of the gasoline present. At the many refineries using this method the highest pressure the writer noted did not exceed 200 pounds, and most of the plants used pressure below 100 pounds per square inch. This is to be expected because the gases treated are almost entirely gasoline vapors and contain but a little permanent gas. Only a few plants compressed in two stages, the greater number used single-stage compression entirely, and relied on a naphtha-absorption system for recovering any gasoline in the residual gas. The naphtha was used in blending the compression gasoline.

In the smaller recovery plants the intake on the compressor can carry the required vacuum on the run-down lines, thus eliminating the need of an exhauster. Although the initial cost of a plant for removing the vapors in this way is lower than that of a plant using an exhauster, the method frequently gives considerable trouble, and hence requires continuous supervision. If the intake of the compressor is used for removing the gases from the run-down lines, the vapors treated are restricted to the sweet gases, those of very low sulphur content. When the sulphur content is high, scrubbing to remove sulphur is absolutely necessary, and as this scrubbing must be done before the gas reaches the compressors, an exhauster is needed to carry the vacuum and to discharge at a pressure high enough to force the gas through the sulphur scrubbers. Several refineries are treating sweet gas only and carrying the sour gas in separate lines to the boilers, where it is burned without the gasoline being removed. Use of an exhauster and a system of sulphur purification would greatly increase the output of this type of recovery plant.

### TWO-STAGE COMPRESSION.

In a plant where gas is compressed in two stages, compressors should be run in such a way as to give each the same load; the power expended in the low-stage cylinder should equal that expended in the high-stage cylinder. Then the temperature of the gas discharged from both compressors will be the same, provided, of course, that the intake temperatures are alike. The best operated plants do this; for instance, in one plant the temperature of the low-stage discharge is 225° F. and of the high-stage 230° F. To maintain this relationship, pop valves set approximately 15 pounds higher than the pressure carried are placed on the discharge line from each compressor. These valves protect the compressor from excess pressures caused by any clogging of the line or closing of valves further along in the system. Figure 10, p. 38, is a diagram of a two-stage compression plant. In the single-stage plant this balance of work is eliminated since the pressure desired is reached in the one machine. The compressors used are of various well-known makes and are generally steam driven, since steam is always available around a refinery. In one plant the compressors were driven by motors of 150 horsepower.

### CONDENSER SURFACE OF COILS.

Evidently for efficient operation the temperature of the gas from each compressor of a two-stage plant must be reduced to approximately intake temperatures. Then the amount of cooling for each stage becomes identical, since the power expended is the same.

In order to obtain this cooling, the temperature of the water and the surface area of the condenser must be the same for each stage. The former is generally constant; therefore the area of condenser surface must be based on the volumes of gas to be cooled. This area in practice is generally about 0.8 square foot of surface per 1,000 cubic feet of gas treated daily. In refineries the volume of gas varies and generally is not metered, consequently determination of the surface area would be rather difficult, and a better relationship to use would be that of surface area to the horsepower required for compression. This figure should be about 4 square feet per horsepower.

### ATMOSPHERIC COOLING.

When the gas is compressed, a little of the heat generated is removed by the water that circulates through the jacket of the cylinder. Then an oil separator removes from the hot gas any lubricating oil carried mechanically or as a vapor. At this point there is atmospheric cooling, and as the separator has a much larger diameter than the line, the velocity of the gas here is much lower. Considerable heat is lost through air cooling along the line from the compressor to the coils, the amount varying with the surface area of the exposed line and the temperature of the atmosphere.

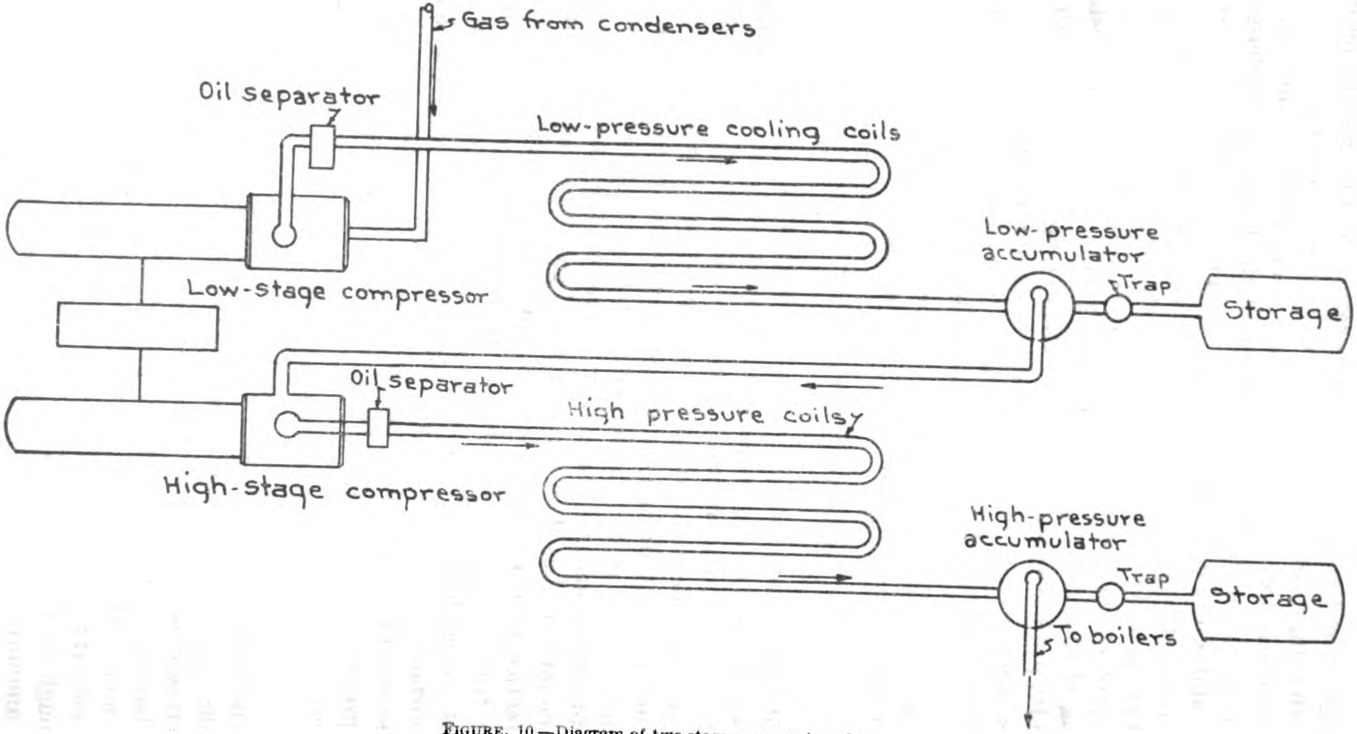


FIGURE. 10.—Diagram of two-stage compression plant.

### TYPES OF COILS.

The hot compressed vapors are condensed by passing through cooling coils, which are of two general types: (1) Submerged type, in which the coils are covered with circulating water in a condenser box, and there is a direct transfer of heat from the gas to the water; and (2) the aerial type, over which water falls as a spray. Better cooling is obtained by the latter type.

A water spray offers a much greater surface for evaporation than water in a condenser box, therefore insures more evaporation and gives lower temperatures. Unless a large supply of cold water is obtainable, the spray system is generally preferable, although the loss of water by evaporation is much higher. In some parts of the country where the humidity of the atmosphere is always high the cooling obtained by evaporation is relatively so small that sprays of water are no more effective than coils submerged in water at the same temperature.

### SPRAY COOLING.

In cooling by spray only a thin film of water should cover the coil. A relatively large stream of water running over the pipe eliminates the possible advantage over submerged cooling, because it hinders rapid evaporation. The larger the water surface exposed the better the cooling. Consequently, just enough water should be circulated to keep the coils wet.

Cooling coils may be sprayed in several ways. The most common method is to use nozzles, discharging upward, a few feet above the coils. The spray may fall directly on the coils or may be distributed to them by means of troughs directly above and overflowing on them. Another method is to use screens through which the water falls on the coils as a fine mist, thus giving to the water the maximum surface for evaporation. These sprays are protected by louver towers that allow circulation of air and also prevent loss of water through wind blowing the sprayed water away.

### CONSTRUCTION OF COILS.

Coils for cooling the compressed gases, like coils for condensing vapors from the stills, are of two general types. In one the gas passes through a single long coil; in the other it is divided by means of a header and is cooled in several lengths of short coils. If the exposed area of pipe is the same, the cooling should be the same in either type, but in the second type some difficulty has been found in maintaining an equal flow of gas through each of the several coils, with the result that some gas is not cooled enough.

In one plant that used three units—three high-stage and three low-stage compressors—all of the gas from the low-stage compressors passed through one set of coils, and the gas from the high-stage compressors was manifolded into one set. Separate coils for each compressor are desirable because in the event of a breakdown only one unit need be shut down, and the gas can be handled temporarily in other compressors. Otherwise, a complete shutdown would result.

### FLOW OF GAS THROUGH COILS.

The gas enters the coils at the top and discharges at the bottom; in consequence, the condensate travels in the same path as the gas. This arrangement is much better than countercurrent gas flow because countercurrent flow would undoubtedly result in much of the condensate being carried away mechanically by the gas.

### ACCUMULATOR TANKS.

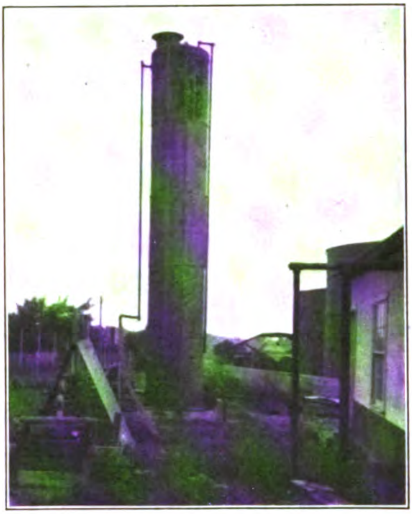
The gasoline recovered by compression and subsequent cooling is collected in a high-pressure tank, generally about 4 feet in diameter and about 9 feet high, which is called an accumulator. It is under the same pressure as the coils. Gage glasses on the tank show the amount of condensate collected. From the accumulator the condensate is blown into the "make tank," where it is blended with naphtha (see Plate VIII, *A*). This blending may be a continuous process, with the naphtha pumped in slowly at such a rate that the desired blend is made, or the necessary amount of naphtha may be pumped in and held there until enough of the condensate has mixed with it to give the blend desired. With the latter method difficulty is often experienced in obtaining an intimate mixture of gasoline and naphtha.

### BLENDING OF CONDENSATE.

At many refineries the blending is done in the accumulator. The blend desired is obtained by pumping in naphtha to a certain height, shown by the gage glass, and allowing the condensing gasoline to mix with the naphtha until the total volume reaches a height, shown by the gage, that has been found to give the right proportions for the desired blend. Another and better method of blending in the accumulator consists of pumping the naphtha through the top of the accumulator and allowing it to fall in a spray or over baffling material, where it absorbs any remaining uncondensed vapors above the condensate. With a predetermined rate of speed the naphtha pumped will, after absorbing gasoline vapor, blend with the compression gasoline to give the mixture desired.

In still another method of blending, the naphtha is pumped into the cooling coils, where it comes in intimate contact with the hot compressed vapors. This method, which has given highly satisfactory results at several plants, yields a better blend because intimate

*A*.—BLENDING TANKS FOR COMPRESSION GASOLINE.



*B*.—NAPHTHA ABSORBER.

*C*. GAS HOUSE WITH ABSORBERS IN REAR.

contact of gas and naphtha is assured during passage through the cooling coils. At the same time, absorption of uncondensed gasoline is effected by contact with the gas throughout the length of the coil. One plant, that had blended in the accumulator by means of a continuous spray falling through the residual gas and subsequently blending with the compression gasoline, recently changed to "hot blending," the introduction of naphtha into the coils. As a result of the change the production for September, 1920, showed an increase of 61 barrels over the highest September production for eight years.

The blended gasoline produced in the compression plants is taken to the gasoline storage where it is mixed with straight-run gasoline. The naphtha used in blending generally has an end point around 437° F., and when blended gives a product with a somewhat lower end point.

TABLE 9.—*Showing distillation range of naphtha, low and high stage compression gasoline and final blend.*

| | Gravity. | Initial. | Per cent off at 212° F. | Per cent off at 221° F. | Per cent off at 275° F. | Per cent off at 302° F. | Per cent off at 356° F. | Per cent off at 400° F. | End point ° F. | Total recovery, per cent. |
|---|---|---|---|---|---|---|---|---|---|---|
| Naphtha | 55.9 | 152 | 9 | 13 | 52 | 68 | 89 | 96 | 406 | 98 |
| Low-stage gasoline | 71.5 | 86 | 77 | 81 | ...... | ...... | ...... | ...... | 239 | 93 |
| High-stage gasoline | 84.5 | 78.8 | 68 | 72 | 74 | 76 | ...... | ...... | 320 | 80 |
| Blend | 60.9 | 97 | 22 | 26.5 | 61 | 71.5 | 86 | ...... | 395 | 97 |

Distillations of raw naphtha and of blended stock are shown in Table 9. The naphtha had a gravity of 55.9° B., and was blended to 60.9° B., with two-stage compression gasoline of 71.5° B. and 84.5° B., respectively, also with the gasoline obtained from the gas by absorption. In the plant from which these figures are taken the blending stock always has a gravity above 52° B. In many plants refining Mid-Continent crude, however, naphtha of a gravity of 50 to 52° B. is used and is blended to about 58° B.

## ABSORPTION PROCESS.

In the absorption process for recovering gasoline from uncondensed still vapors the vapors are brought into intimate contact with an absorbent oil, which takes into solution the gasoline and some of the permanent gases in the vapors. A flow sheet of a naphtha-absorption system is shown in Figure 11. When a naphtha of about 50° B. is used the product has a gravity of 56° or 57° B., and is pumped directly to the gasoline storage. A gas oil of about 35° B. may be used as an absorbent and the gasoline subsequently removed by steam or fire distillation. The stripped gas oil is returned to the absorption plant and used again.

In most absorption plants treating refinery vapors, the gases are collected by an exhauster which discharges under enough pressure to force the gas through the absorption tower. These towers differ greatly in size because of differences in the volume of gas to be treated and the pressure on the gas. As will be shown later, low-pressure absorption in a refinery is more practicable than high-pressure absorption, which necessitates the use of large towers.

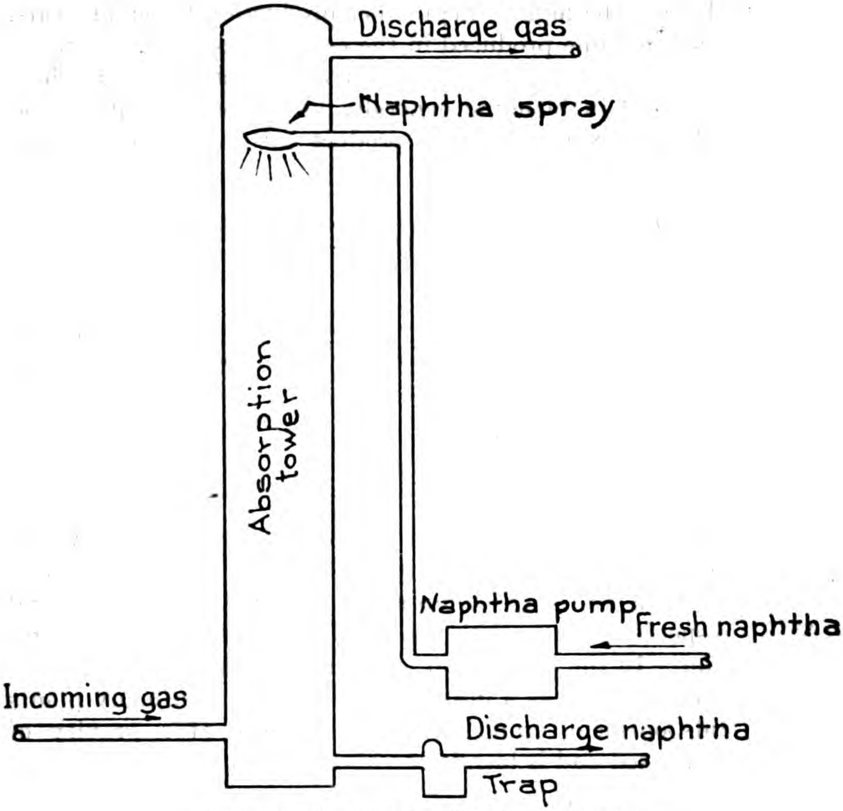


FIGURE 11.—Flow sheet of naphtha-absorption system.

## ABSORPTION IN NAPHTHA.

In one plant where naphtha having a gravity of 50° B. is used as the absorbent, five 10 by 30 foot towers are employed for treating about 1,000,000 feet of gas daily. These towers have steel baffles and cone plates, the baffles containing 22 circles of 5-inch holes drilled 2 inches apart.

The gas enters the bottom of the first absorber, discharges at the top, passes to the bottom of the second absorber, and so on through the series. Pumps keep the naphtha moving countercurrent in each

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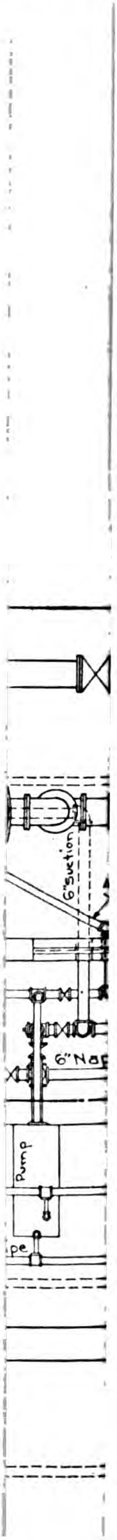
6" suction
6" Nap
Pump
pe

absorber until the gravity of the naphtha in the last absorber has reached the point desired. Then the blend from this tower goes to storage and the naphtha from each tower moves to the next tower, where the same process is repeated.

In another method of absorption which is more generally used the gas and naphtha flow countercurrent through a series of towers. This method has the advantage over the method previously described in that the naphtha is handled only once and at its discharge has the gravity desired, but the method has peculiar difficulties not experienced in the first type of plant, for the gasoline content of the gas being treated varies widely and in consequence the rate of flow of the naphtha must be watched carefully to insure a uniform product. Plate IX gives detail drawings of the piping layout of an absorption plant. Plate VIII, *C*, p. 40, shows an absorption plant with absorbers in the rear of the gas house.

### ABSORPTION IN GAS OIL.

An absorption plant using a gas oil as absorbent resembles the absorption plant of the natural-gas gasoline industry rather than a naphtha-absorption plant. The gas oil circulates continuously through the absorbers, where it dissolves the gasoline vapors. As in the naphtha-absorption system already described, oil flows countercurrent to the gas in vertical absorbers filled with baffling material to spread the oil over a large surface and insure intimate contact of gas and oil. From the absorbers the oil is pumped to a steam still, where live steam strips it of the absorbed gasoline, which is condensed in cooling coils and taken to storage. The hot oil from this still passes through a series of heat exchanges countercurrent to the cold oil coming to the still, is further cooled by spray towers, and then enters the absorbers to start another cycle.

In one plant the gas oil containing the absorbed gasoline went directly to the pressure stills, where the gasoline was recovered with the cracked distillate.

The use of gas oil as an absorbent entails much additional expense for removal of the gasoline; the use of naphtha does not, because when the gravity is raised to the desired point the product can be pumped directly to the gasoline storage. In the natural-gas gasoline industry naphtha for blending is difficult to procure, and frequently the price paid for it, together with freight charges, equals or exceeds the price obtained for the finished product. Most absorption plants treating natural gas use a refined gas oil, such as mineral seal, instead of naphtha, because gas oil is a more efficient absorbent and absorption gasoline commands a higher price than naphtha blends. Consequently naphtha is not used as an absorbent except in compression plants, where it is required for blending, and there it is frequently used as an absorbent in treating residual gases. In refineries where gasoline can be recovered from the gases, however, naphtha absorption is probably the more advantageous; the factors of price and transportation do not have to be considered, and the gases treated are much richer in higher hydrocarbons than is natural gas, which contains only a small percentage of gasoline vapor. As the uncondensed still vapors carry so much gasoline, their absorption in naphtha is much more efficient than is the absorption of gasoline from natural gas. At a refinery using naphtha absorption the naphtha is cut from the crude stills and after passing through the absorption system is pumped to the straight-run gasoline storage. The only expense involved is that of pumping. Plate VIII, *B* (p. 40), shows a naphtha absorber in a small skimming plant.

In the plant previously cited, where gas oil passed through the absorption system to the pressure stills, the same advantage is obtained in so far as the use of gas oil involved no additional expense. It is quite possible, however, that a considerable percentage of the absorbed gasoline would be lost either by being broken down into permanent gas or by being carried away with the cracked gases.

### EFFECT OF TEMPERATURE ON ABSORPTION.

In the absorption process the temperature in the tower must be closely regulated because the absorbing power of naphtha or gas oil (especially the former) is much decreased by a rise in temperature. This decrease in absorbing efficiency is not pronounced at temperatures lower than about 85° F., but above that figure the efficiency of absorption falls rapidly. It is true, also, that although a lowering of the temperature in the absorption towers increases their efficiency, the increased recovery largely represents hydrocarbons that can not be considered gasoline and can never be saved as such. In consequence, excessive weathering losses occur when the naphtha reaches normal temperature or when the gas oil is sent to steam stills. Not only is the increased absorption obtained from lower temperature lost by subsequent evaporation but a large amount of gasoline is mechanically carried away by the permanent gases that escape.

The temperatures of the absorbent and of the gas should be well below 85° F. and should not differ greatly. When gasoline vapor is absorbed by naphtha or gas oil, enough heat is given off to raise the absorber temperature above 85° F. if the temperature of the gas and gas oil is not well below that figure.

Temperatures below 85° F. can generally be obtained by passing the gas through water traps, as described elsewhere, but in many plants a louver tower for cooling the gas and oil would be advantageous and would materially increase production. A recovery system for the uncondensed still vapors is especially necessary in refineries with inefficient condensers. Therefore the gas obtained at this source will always have a rather high temperature, particularly if the gas risers pass directly upward through the water in the condenser box. The absorbing oil will never be cooler than the atmosphere and frequently when taken directly from the manifolds will be much warmer.

### VOLUME OF GAS AND SIZE OF ABSORBERS.

In the refinery the gas is delivered to the absorption plant at a very low pressure, and large absorption towers are necessary to handle the volume of gas produced. The pressure and temperature of the gas determine the actual volume that must be treated, and this in turn determines the diameter of tower for proper velocity of gas flow. If gas has too high velocity, oil is carried over with gas. Dykema[7] says that velocities through absorption towers should not exceed 75 feet per minute.

The height of the tower largely determines the length of time and intimacy of contact between the gas and the absorbent, which in turn governs the saturation of gasoline obtainable in the absorbing oil.

The absorption towers shown in Plate X are 10 feet in diameter and 30 feet high. The velocity of the gas passing through is about 65 feet per minute, but necessarily varies with the volume of gas produced. Variations in volume of gas must be considered in designing an absorption plant; they will be greater in a refinery than in a natural-gas gasoline plant using the absorption process.

### TYPES OF BAFFLING USED IN ABSORBERS.

The absorption plants visited used several types of baffles; in one the baffles were wooden grids, in another perforated plates, and in another chemical tile. In natural-gas gasoline plants all these types of baffling have been employed, as well as steel shavings, crocks, and tin cans. The main object, of course, is to have baffling material which will give a maximum surface with a maximum void space. Some of the best baffling materials, however, have disadvantages, especially in the treatment of refinery gases. These gases usually contain more sulphur than ordinary natural gas, and hence the use of wooden and earthenware baffling is imperative. In a recent publication[8] the Bureau of Mines has pointed out the excellence of Raschig rings as baffling material. The following table is quoted for the reader's information.

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[7] Dykema, W. P. Recent developments in the absorption process for removing gasoline from natural gas: Bull. 176, Bureau of Mines, 1919, 90 pp.

[8] Dykema, W. P., and Neal, R. O., Absorption as applied to recovery of gasoline in residual gas from compression plants: Tech. Paper 232, Bureau of Mines, 1920, p. 25.

TABLE 10.—*Approximate factors for representative baffling material.*

| Material. | Weight per cubic foot. | Surface exposed per cubic foot. | Voidage. |
|---|---|---|---|
| | *Pounds.* | *Cubic feet.* | *Per cent.* |
| Raschig rings | 35 | 60 | 70 |
| Clay tubes, 4 by 3 inches | 112 | 32 | 35 |
| Steel shavings | 57 | .......... | .......... |
| Crushed rock | 100 | .......... | .......... |
| Lathing | 15 | 22 | 69 |

Raschig rings are made of glazed clay; they are 1 inch long, 1 inch in diameter, and have walls $\frac{1}{8}$ inch thick. To fill a tower the rings are merely thrown in without regard to the position they may take.

### CHARCOAL ABSORPTION.

Charcoal is used as the absorbing medium in a process developed recently. The gas is led through towers filled with activated charcoal, which first absorbs all of the hydrocarbons and then causes the lighter members to be replaced by heavier ones. When the limit of absorption is reached, live superheated steam is turned into the absorber and the gasoline contained is driven out. Many advantages are claimed for this method, but up to March, 1923, no commercial plants had been installed for treating still vapors at refineries, although some installations are treating natural gas.

Results obtained by Engelhardt [9] show that gases containing hydrogen sulphide and oxygen yield free sulphur when passed through activated charcoal. In a recovery plant this reaction would be undesirable, for the charcoal would soon be clogged with free sulphur. Refinery gases generally contain both air and an appreciable amount of hydrogen sulphide, thus meeting the conditions described by Engelhardt.

## ECONOMICS OF RECOVERY OF UNCONDENSED VAPORS.

As shown previously, certain factors are responsible for the noncondensation of gasoline vapors, and the question rises whether in attempts to reduce the loss it will be more economical to change plants already built than to install a plant for recovering the vapors as gasoline. A recovery plant is in reality a secondary condensing system—an auxiliary to the primary condensers. This means that if temperature of the gas from the condensers could be kept low enough the recovery plant would be of small advantage.

Maintenance of a low temperature in the gas stream, however, depends on cold water and a large condenser area. Loss of gasoline due to the high temperature of the stream raises an economic problem—whether enlarging the condensers, obtaining colder and larger supplies of water, or building a secondary condensing system in the form of a compression or absorption plant would be least expensive.

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[9] Engelhardt, A., Activated carbon converts $H_2S$ into S: Gas Age Record, vol. 48, Sept. 10, 1921, p. 275.

The quality of the crude must also be considered, for if the crude contains only a very small proportion of the lighter hydrocarbons, condensers that are too small and not cooled enough to handle the large volume of light vapors from a high-gravity crude can handle the small volume of vapors from a low-gravity crude.

Plants having pressure stills in operation offer another problem, for the gases formed in cracking are permanent and can never be recovered as gasoline. In a cracking process where the pressure is not released until the vapors have passed through the condensers, all of the gasoline vapor worth recovering is condensed and the uncondensed gas remaining has so low a gasoline content that its treatment need not be considered. In a cracking process where the distillates condense at atmospheric pressure the condensation of the very light vapors depends entirely on the condenser area and the temperature of the cooling water. Another feature to be noted in considering the installation of a recovery system is that by lines run to storage tanks containing crude oil and gasoline large quantities of vapor can be recovered that would otherwise evaporate and be lost. Wiggins [10] has shown that a comparatively high percentage of gasoline and crude oil in storage is lost through evaporation, and that the part which evaporates from crude represents the most volatile and most valuable fractions.

At plants already in operation it is obviously much cheaper to install a compression or absorption plant for condensing the gasoline as a vapor than to enlarge condensers, especially where cold water is scarce. Probably no other expenditure in a refinery will give a quicker return than that required for a recovery plant. One refinery, for example, paid for the recovery plant by operating two months. This could not be done in every refinery, but if all the factors mentioned are considered before the plant is installed, appreciable quantities of gasoline can undoubtedly be saved.

## TESTING VAPORS IN PLANT PREVIOUS TO THE INSTALLATION OF A RECOVERY SYSTEM.

Although probably all refineries suffer losses of gasoline in uncondensed still vapors, it would be poor policy to erect a recovery plant without prior knowledge of the amount of gas to be treated and the possible recovery to be effected by the proposed recovery system. In general, a much more thorough investigation will be required than in testing a natural-gas gasoline property, since the quality of the gas changes continually and the volume varies widely. Consequently all factors must be taken into consideration. The volumes of gas produced from all stills, under different operating conditions, should be measured and the vapors subjected to compression or absorption tests, so that by the end of the investigation, definite knowledge will be available regarding the volume of gas to be treated and the quantity of gasoline that might be produced. On these data the plant can be planned to meet requirements. Since the recovery of gasoline from uncondensed refinery vapors is an outgrowth of the processes used in the extraction of gasoline from natural gas, the methods of testing natural gas for gasoline content can be applied in testing uncondensed still vapors.

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[10] Wiggins, J. H., Evaporation losses of petroleum in the Mid-Continent field: Bureau of Mines, Bull. 200, 1922, 113 pp.

### SPECIFIC-GRAVITY TEST.

Formerly the specific-gravity test was used as a determination of the gasoline content of a gas, but the development of the natural-gas gasoline industry has caused the test to be discarded for this purpose, and it is now used only as a preliminary test. If a gas shows a high specific gravity, no great faith is placed on the indicated gasoline content until this is actually determined by a better method.

In a refinery where the uncondensed still vapors may carry 2 or 3 to 30 gallons of gasoline per 1,000 cubic feet, frequently having a high sulphur content and containing varying proportions of air, the gravity test is of much less value than in a plant for treating natural gas.

The gravity test is made by noting the time a given volume of gas passes through a small orifice and comparing it with the time taken by the same volume of air. If the time required for the gas to pass through the orifice is squared and divided by the square of the time required for air to pass through the same orifice, the result will be the specific gravity of the gas (assuming air = 1). The test is made in a special apparatus consisting of a graduated glass tube supported vertically in a jar of water. The tube is filled with gas and the time taken by the gas in passing through the orifice is noted.

### COMPRESSION TEST.

A small compressor which generally compresses a metered volume of gas to about 250 pounds, is used in making the compression test. The gas is cooled in passing through a condenser tube submerged in cold water; the gasoline condensed is collected in an accumulator, whence it is drawn off, weathered, and then measured. This test is convenient and rapid and is accurate enough for the purpose.

### ABSORPTION TEST.

An absorption test is made by passing a metered volume of gas through an apparatus filled with an absorbing oil that has a rather high initial boiling point, for instance, mineral seal oil (b. p. 470° F.). By bringing the gas in intimate contact with the oil, practically all the gasoline vapor is absorbed. Then the oil is removed from the apparatus and distilled; the gasoline is recovered and measured. From these data the gasoline content of the gas can be determined.

### CHARCOAL TEST.

In the charcoal test a metered volume of gas is passed through a small tube holding about 250 c. c. of activated charcoal, which adsorbs the gasoline vapors, removing them from the gas. After the adsorption, the charcoal is taken out and put in a flask containing glycerin. All of the gasoline is distilled from the glycerin by heating, and is then collected and measured.

### MEASUREMENT OF VOLUMES.

To measure exactly the volumes of gas remaining uncondensed is rather difficult, since volumes, of course, will vary with different conditions. However, by suitably connecting a meter to the rundown line from the condenser all of the gas can be trapped and metered. The meter should be left on the gas flow long enough to indicate the average amount of uncondensed vapor under the various prevailing conditions. Similar measurements should be made on all of the run-down lines from the stills producing gas, and from the data obtained some definite idea can be had of the volume of gas available for treatment in a recovery plant.

### SAMPLING GAS FOR SULPHUR DETERMINATIONS.

At some refineries the still vapors have a very high sulphur content, and a gasoline-recovery system would necessarily have to include a scrubber for removing sulphur. Samples of gas from various stills should be taken at different times under various operating conditions in order to obtain by a subsequent chemical analysis exact information on sulphur content.

An excellent container for a gas sample is a bottle such as is used for dispensing magnesium citrate; it can be filled easily by allowing a stream of gas to flow into it through a rubber tube for several minutes or until the gas has displaced all the air. Then the bottle should be quickly closed.

The gas is analyzed for sulphur by passing a known volume through a standard iodine solution, which later is titrated to determine the amount of sulphur compounds. The result is generally expressed in grains of sulphur per 100 cubic feet of gas. If the sulphur content of the gas runs less than 500 grains per 100 cubic feet, there will be no trouble from precipitation of sulphur in the lines or in the compressors

## COSTS OF PLANTS.

### COST OF CONSTRUCTION.

To estimate the cost of installing a gasoline-recovery plant is difficult. Costs vary with local conditions, such as distances between the different stills that are the sources of the gas; the nature of the gas, especially its sulphur content; and with the efficiency of the plant. However, a cost of approximately $15 per gallon of gasoline (daily capacity) should, in the opinion of the writer, be ample. This is much lower than the cost of the average plant for recovering gasoline from natural gas or casing-head gas, but the cost of a recovery plant at a refinery is lower, because gathering lines and gasoline lines are much shorter, tankage and loading racks are already provided for, and the plant will have a supply of gas as long as the refinery is in operation. In the natural-gas gasoline industry only a few years' supply of gas can be expected from one source. Based on a recovery of 1 per cent of gasoline from the total charge of crude, the cost of construction when applied to the daily refinery capacity would be approximately $4 per barrel of crude charged.

One plant that the writer saw was so situated that the gathering lines were very long, and tests after the completion of the plant showed that a large amount of gas from the pressure stills could not be used unless a plant to remove sulphur was installed. In consequence operations were confined to sweet gas, thus cutting down the possible output of gasoline and making the cost of installation, since the investment in unused lines remained the same, about $50 a gallon (daily capacity) of gasoline.

### COST OF OPERATION.

The operating cost of a gas plant is relatively low. Generally not more than two men are required on a tour and at many plants only one man is in charge of the compressors or exhausters. In the average plant a cost of about 1½ cents per gallon is charged to operation, which includes wages and the cost of steam. One refinery shows a cost of 4 cents a gallon, but largely because the charge made for steam is high. At an average plant the cost of labor for operation would be about the same as at a natural-gas gasoline plant. At practically all natural-gas gasoline plants, however, the cost of gas is a large item, whereas in refineries the gas has no particular value; in fact, the gasoline must be removed before the gas can even be burned successfully under boilers or stills.

## STILL VAPORS AS A SOURCE OF VARIOUS PRODUCTS.

### MANUFACTURE OF ALCOHOLS FROM STILL GASES.

As temperatures and pressures in cracking stills are high, the products obtained carry a high percentage of unsaturated hydrocarbons. Even the gases that remain uncondensed contain as much as 8 per cent of olefins. Ellis [11] has investigated the possibilities of manufacturing various alcohols, esters, and ketones from the uncondensed gases from cracking stills. The process used consists of removing hydrogen sulphide and water vapor, then treating the gas with sulphuric acid of 1.8 specific gravity. A certain amount of alkyl sulphuric acid is produced which, under these conditions of formation, looks like a brown sirup, and, with the excess sulphuric acid, has a specific gravity of about 1.4. This sirup in turn is hydrolized by mixing with several volumes of water; subsequently the alcohol is distilled from the water extract and rectified to the desired purity. During the absorption of gas by the acid a small refrigeration plant maintains the temperature at about 68° F. The alcohol produced consists of 90 per cent isopropyl alcohol and 10 per cent water, is very valuable as a solvent, and can be used in place of methyl and ethylalcohol for most commercial purposes.

The chemical reaction is as follows:

$$CH_3.CH{:}\,CH_2+H_2\,SO_4-CH_3.CH_3{:}\,CH_2SO_4$$

Propylene+sulphuric acid−propylsulphuric acid

$$CH_3.CH_3{:}\,CH_2SO_4+H_2O-CH_3.CHOH.CH_3+H_2SO_4$$

Propylsulphuric acid+water−propyl alcohol+sulphuric acid.

Acetic esters can also be produced by treating the alkyl sulphuric acid with sodium acetate. By catalytic oxidation, or dehydrogenation, acetone can be formed. This process offers great possibilities in the manufacture of organic chemicals from the by-products of petroleum refining.

## SUMMARY.

The information given in this paper may be briefly summarized as follows:

1. In the distillation of crude oil in refineries appreciable volumes of the vapors are not condensed by the ordinary equipment. The amount of vapor remaining uncondensed depends on these factors:

(*a*) The amount of gasoline produced. Other conditions being equal, more uncondensed vapor will be lost in a refinery which has increased the gasoline yield from crude by installing cracking stills than in a skimming plant obtaining only the gasoline naturally present in the crude.

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[11] Ellis, Carleton, Petrol-alcohol chemical discovery: Petrol. Mag., vol. 10, Jan., 1921, pp. 40–41.

(*b*) The character of the crude. The loss in uncondensed vapors will be larger from a crude yielding high-volatile gasoline than from a crude yielding low-volatile gasoline.

(*c*) The weather. Losses due to uncondensed vapors are higher in summer than in winter.

(*d*) The higher the temperature of the stream the greater is the amount of uncondensed vapor. Stream temperature depends directly on the temperature of the cooling water and the coil surface. When stream temperatures exceed 85° F. the volumes of uncondensed vapors become increasingly large. Experimental and plant data show the effects of varying conditions of temperature.

2. At refineries in the United States that recover gasoline from uncondensed vapors a survey shows: A total crude charge of 355,486 barrels a day, a recovery of gasoline from uncondensed vapors of 128,651 gallons a day—an average recovery of 0.444 gallon of gasoline per barrel of crude—or the recovery of 1.05 per cent of the crude as gasoline that would otherwise be lost.

3. Methods for collecting the vapors at a recovery plant are shown. A small vacuum is held by the intake of the compressor or by an exhauster on run-down lines where the vapors are trapped off by goosenecks. This gas passes through traps that remove any condensate carried in the lines.

4. If the sulphur content of the gas is high, the sulphur must be removed in a special unit, either by scrubbing with a solution of caustic soda or by contact with oxides of iron or lime suspended in water.

5. Several different processes can be used to recover gasoline from still vapors:

(*a*) Compression is the more common process. The gas is compressed to a high pressure and cooled. Gasoline vapors are condensed and collected but any permanent gas present is not materially affected.

(*b*) In the absorption process the gas is passed through a distillate of lower Baumé gravity that absorbs the gasoline. When naphtha is used as the absorbent the naphtha is raised in Baumé gravity to the point where it may be marketed as gasoline. When a heavy gas-oil distillate is used, the gasoline is recovered from the gas oil by distillation.

(*c*) A combination of the two methods is used when the gas after compression is passed through absorption towers.

6. Some general figures are presented to show the cost of a recovery plant for a refinery of given capacity.

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